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March 1993

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US Army Corps
of Engineers
Waterways Experiment
Station

St. Stephen Powerhouse Fish Lift, Cooper River Rediversion Project, South Carolina

Hydraulic Model Investigation

by Thomas E. Murphy, Jr., John E. Hite, Jr.
Hydraulics Laboratory

Prepared for U.S. Army Engineer District, Charleston

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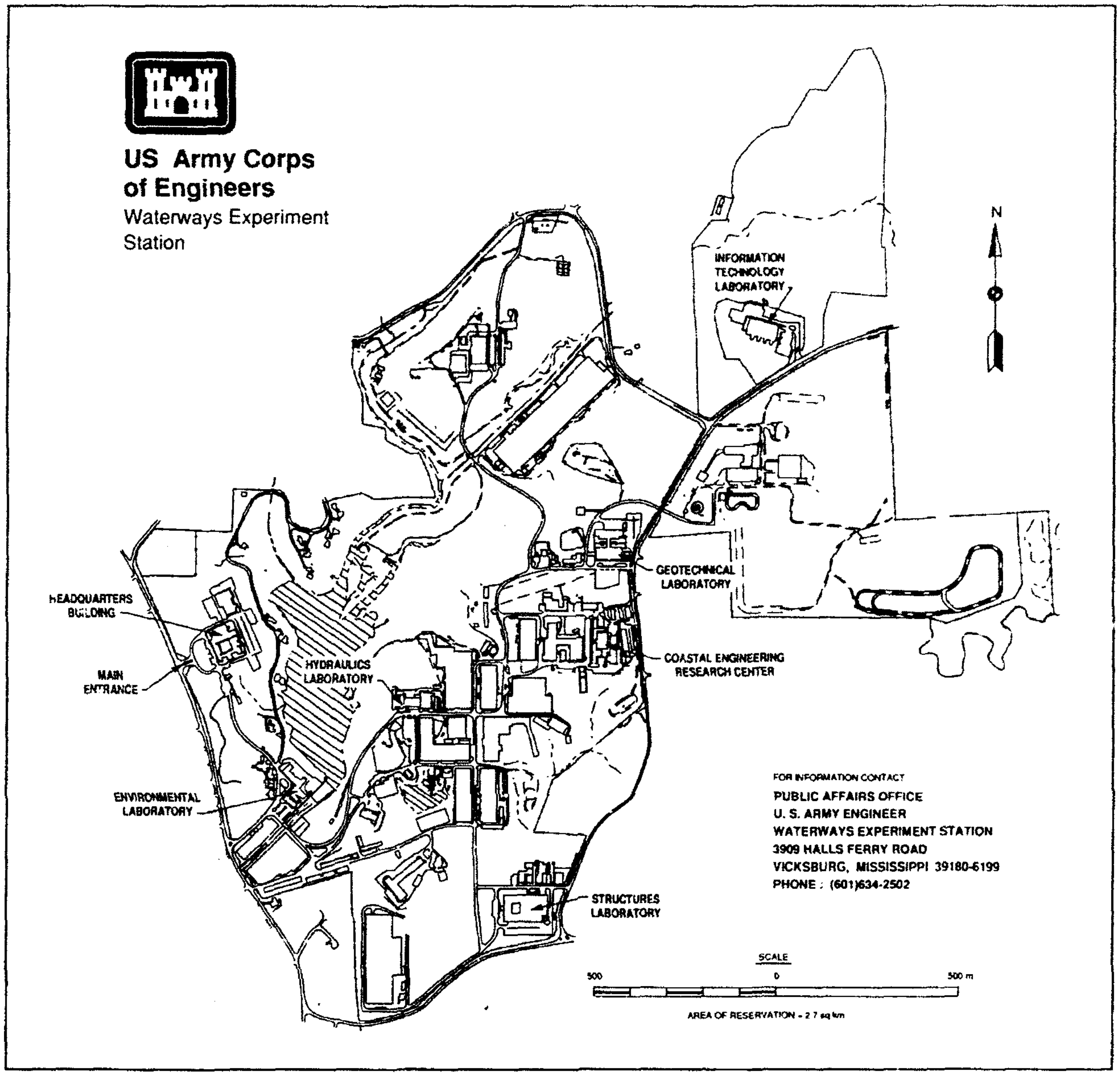

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PREFACE

The model investigation reported herein was authorized by Headquarters, US Army Corps of Engineers, on 26 March 1991 at the request of the US Army Engineer District, Charleston (SAC). The studies were conducted at the US Army Engineer Waterways Experiment Station (WES) during the period September 1991 to March 1992. All studies were conducted under the direction of Messrs. Frank A. Herrmann, Jr., Director of the Hydraulics Laboratory, WES; Richard A. Sager, Assistant Director of the Hydraulics Laboratory; and Glenn A. Pickering, Chief of the Hydraulic Structures Division, Hydraulics Laboratory. Tests were conducted by Mr. Thomas E. Murphy, Jr., Dr. John E. Hite, Jr., Mr. Robert A. Davidson, and Ms. Olie Blansett, all of the Locks and Conduits Branch, Hydraulic Structures Division, under the supervision of Mr. J. F. George, Chief of the Locks and Conduits Branch. This report was prepared by Mr. Murphy and Dr. Hite and edited by Mrs. Marsha C. Gay, Information Technology Laboratory, WES.

During the course of the investigation, Messrs. James Joslin, Charles Harbin, Millard Dowd, Richard Jackson, Francis Limbaker, and William McCollum of SAC; Messrs. Douglas Cooke and Samuel Chappelear of the South Carolina Wildlife and Marine Resources Department; and Mr. Ben Rizzo of the US Fish and Wildlife Service visited WES to observe model operation and correlate results with design studies.

At the time of publication of this report, Director of WES was Dr. Robert W. Whalin. Commander was COL Leonard G. Hassell, EN.

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CONVERSION FACTORS, NON-SI TO SI (METRIC)
UNITS OF MEASUREMENT

Non-SI units of measurement used in this report can be converted to SI (metric) units as follows:

Multiply	By	To Obtain
cubic feet	0.45359244	kilograms
feet	0.3048	metres
miles (US statute)	1.609344	kilometres

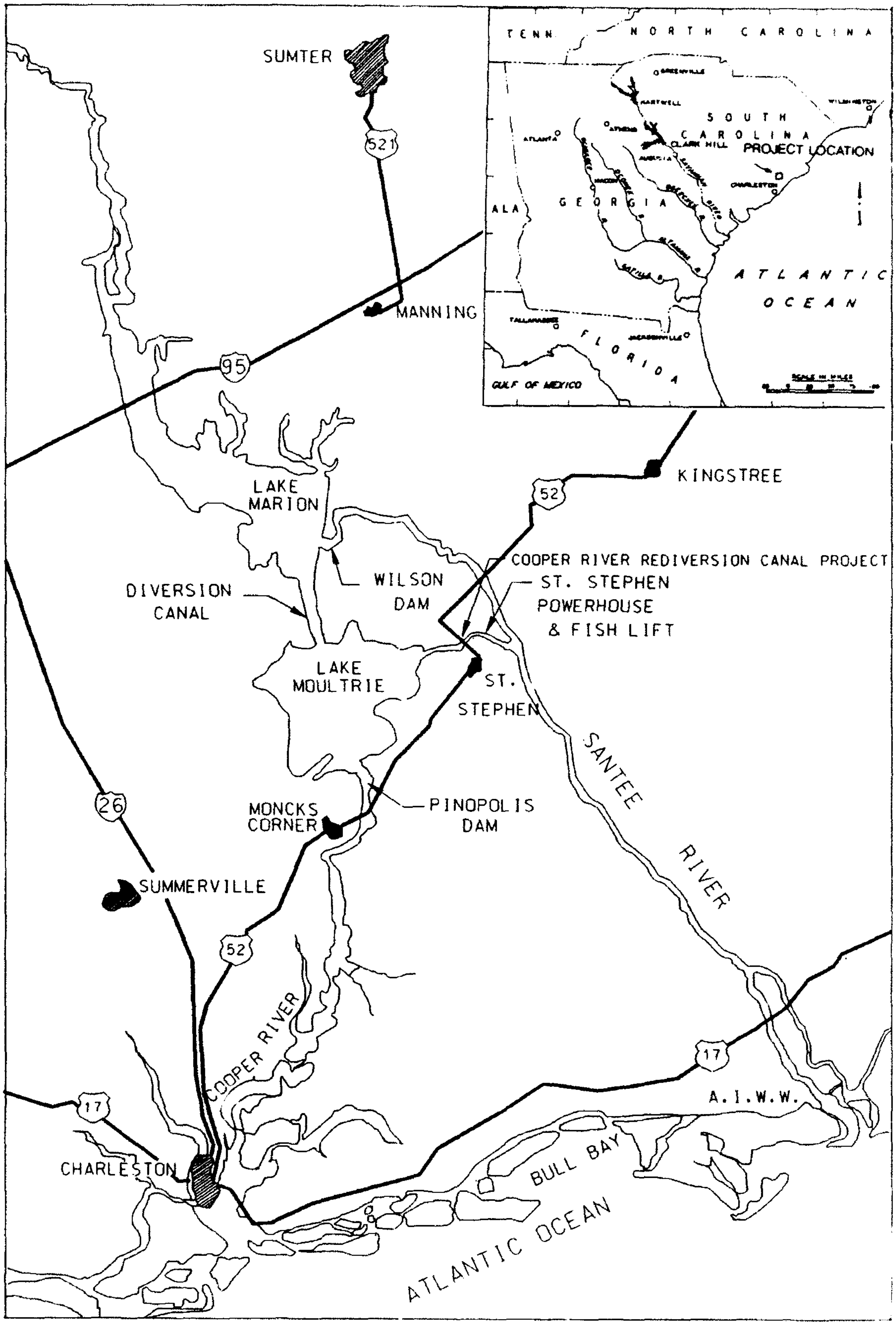

Figure 1. Vicinity and location map

ST. STEPHEN POWERHOUSE FISH LIFT

COOPER RIVER REDIVERSION PROJECT, SOUTH CAROLINA

Hydraulic Model Investigation

PART I: INTRODUCTION

Background

1. The St. Stephen Power Plant is located in Berkeley County, South Carolina, approximately 1.9 miles* north of the town of St. Stephen (Figure 1). It is located in the rediversion canal connecting Lake Moultrie and the Santee River. The powerhouse consists of three main units, each rated 28 Mw. The overall length of the powerhouse is 276 ft and the transverse width is approximately 150 ft at the base.

2. The fish lift facilities, located on the north side of the powerhouse, were intended to provide a means of transferring various species of game and other desirable fish from the power plant tailrace canal to the intake canal and Lake Moultrie. After several years of fish lift operation at St. Stephen Powerhouse, it was determined that the present facilities were inadequate for transferring the numbers and species of anadromous fish using the St. Stephen tailrace as a migration route to Lake Moultrie. The present fish lift does not provide attraction flow in the tailrace area, where the desired numbers of fish are likely to be drawn into the fish lift.

Purpose and Scope of the Model Study

3. The purpose of the study was to investigate various alternatives to improve the fish attraction capabilities of the existing fish lift system. Specific model tests were conducted to

- a. Determine if increasing the attraction flow through the present fish lift would provide the type flows necessary for proper fish attraction.
- b. Investigate means of relocating the fish lift entrances to

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* Non-SI units of measurement used in this report can be converted to SI (metric) units as shown on page 3.

areas that would be more likely to attract migrating fish into the fish lift system.

c. Determine if structural additions in the tailrace would adversely affect present hydraulic conditions in the tailrace area.

PART II: THE MODEL

Description

4. The model was constructed to an undistorted scale of 1:25 and reproduced about 1,700 ft of the tailrace topography, the downstream face of the powerhouse, intake piers, spiral cases, draft tubes, and the existing fish lift entrances. The tailrace walls, tailrace slab, downstream face of the powerhouse, and portions of the fish lift were constructed of plastic-coated plywood. The spiral cases, draft tubes, and fish lift entrance piers were constructed of smooth Plexiglas. The downstream topography was constructed of sand and cement mortar molded to sheet metal templates. Plate 1 is a layout of the model. Figure 2 shows the model. Figure 3 is a side view of an intake, spiral case, and draft tube for a powerhouse unit.

Model Appurtenances

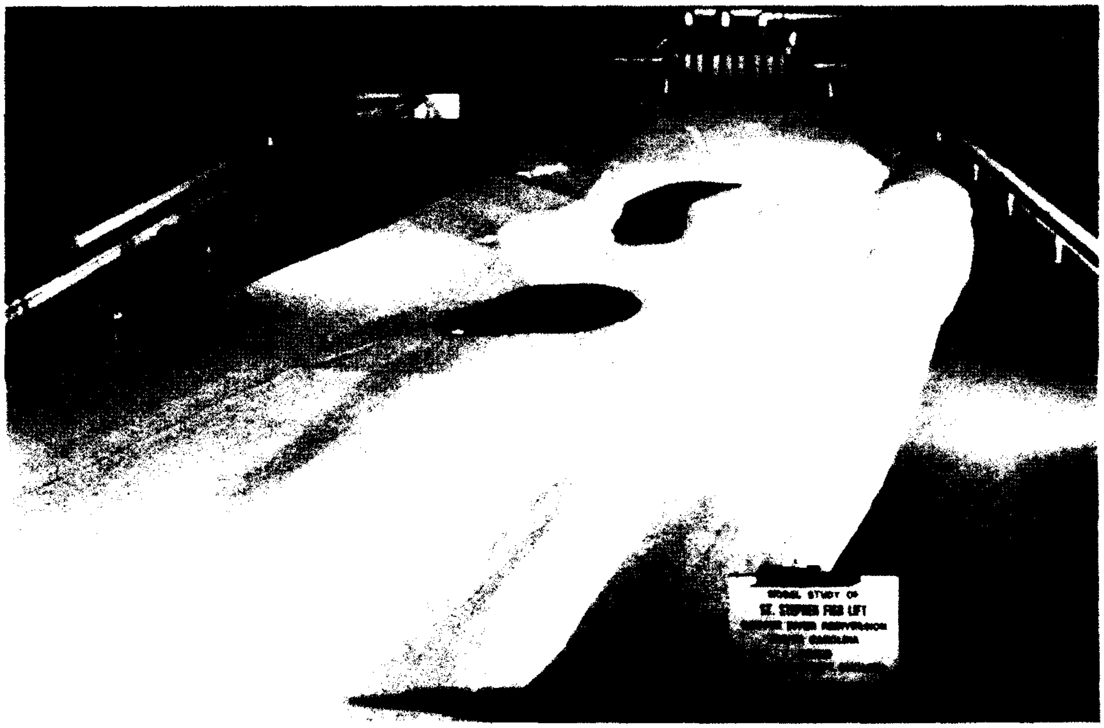
5. Water used in operation of the model was supplied by a circulating system. Discharges in the model were measured with venturi meters and propeller type flowmeters installed in the inflow lines. Water-surface elevations were measured with point gages. Average velocities were measured with a Nixon streamflow series 400 propeller type flowmeter, mounted to permit measurement of flow from any horizontal direction and at any depth. The tailwater elevation was maintained with an adjustable tailgate. Various flow conditions were recorded photographically.

Scale Relations

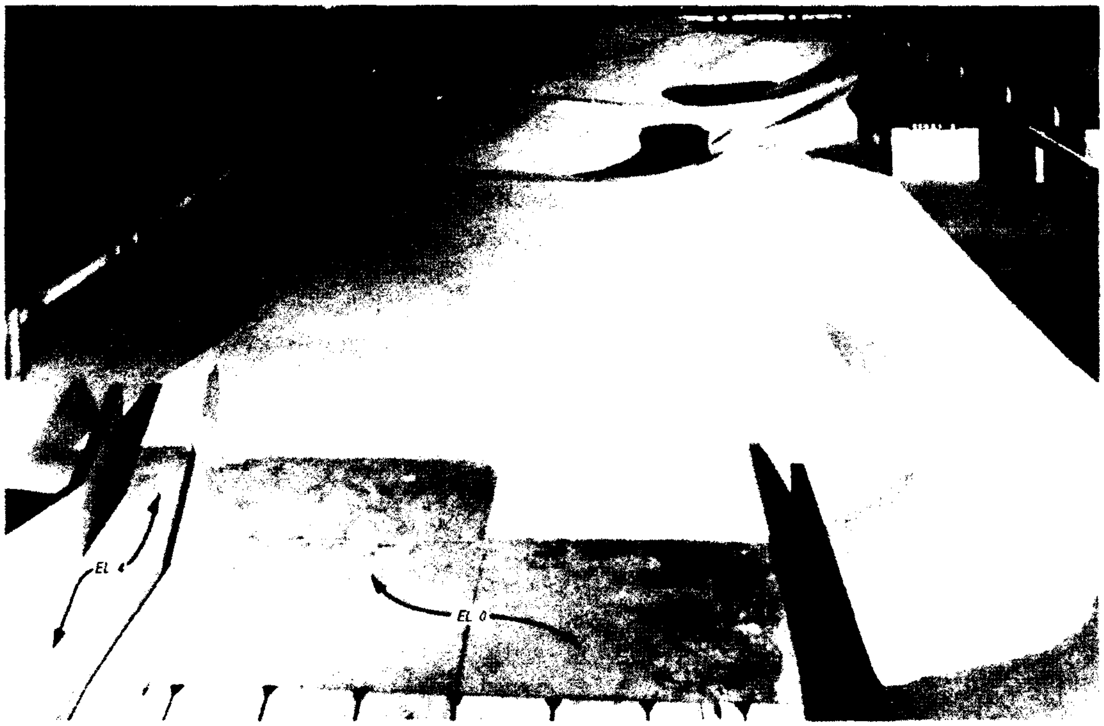
6. The accepted equations of hydraulic similitude, based on the Froudian criteria, were used to express mathematical relations between the dimensions and hydraulic quantities of the model and prototype. General relations for the transference of model data to prototype equivalents are presented in the following tabulation:

Characteristic	Dimension*	Scale Relationship Model:Prototype
Length	L_r	1:25
Area	$A_r = L_r^2$	1:625
Velocity	$V_r = L_r^{1/2}$	1:5
Discharge	$Q_r = L_r^{5/2}$	1:3,125
Volume	$V_r = L_r^3$	1:15,625
Weight	$W_r = L_r^3$	1:15,625
Time	$T_r = L_r^{1/2}$	1:5

* Dimensions are in terms of length.

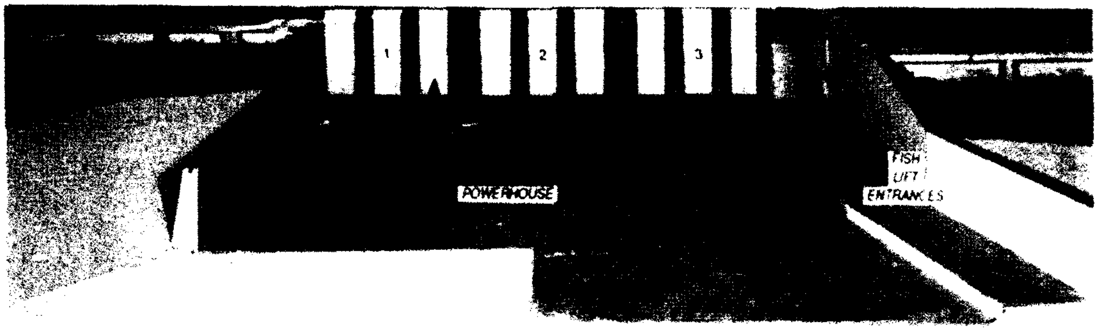


a. Looking upstream

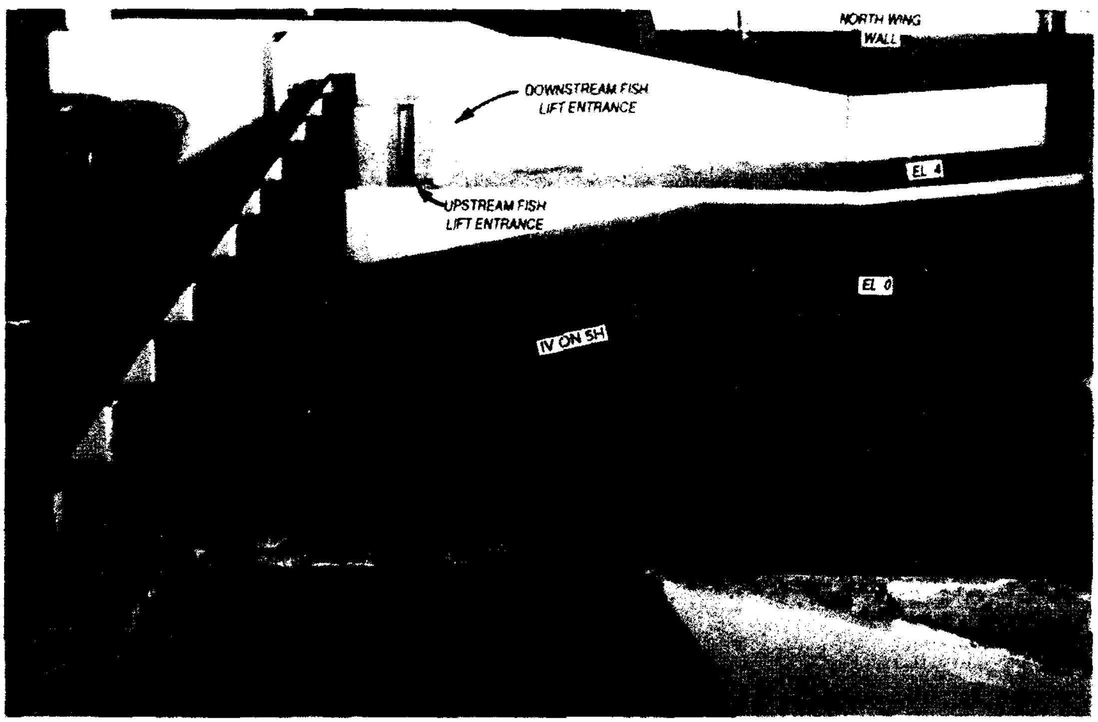


b. Looking downstream

Figure 2. 1:25-scale model of St. Stephen Powerhouse tailrace (Continued)



c. Looking upstream toward powerhouse and fish lift entrances



d. Side view looking toward north wing wall and fish lift entrances

Figure 2. (Concluded)

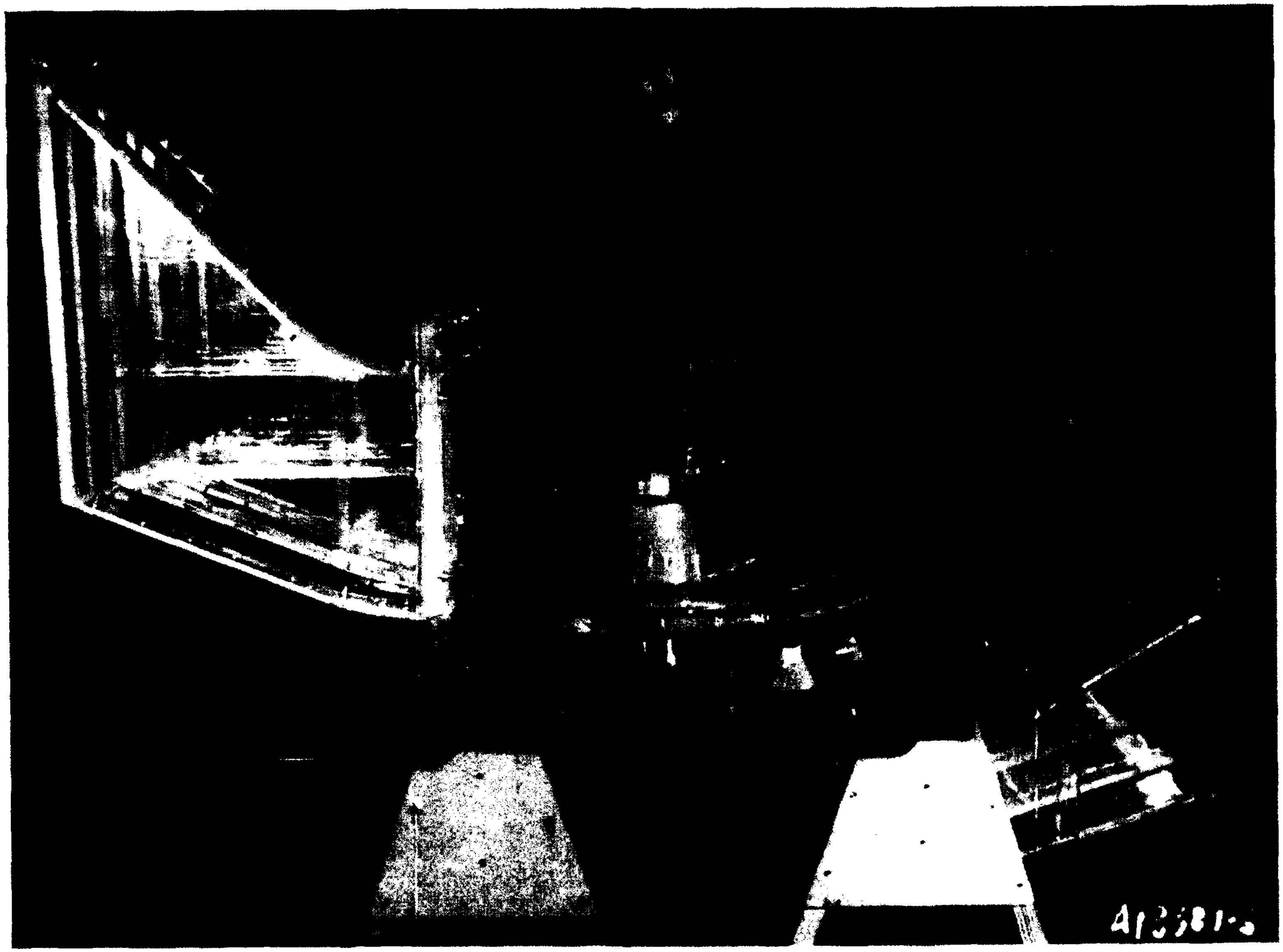


Figure 3. Side view of 1:25-scale intake, spiral case, and draft tube for a powerhouse unit

PART III: TESTS AND RESULTS

Original Design

Fish attraction flow of 240 cfs

7. Initial tests were conducted with the original design to determine flow patterns in the tailrace with various combinations of powerhouse units operating and a total fish attraction flow of 240 cfs through both fish entrances. Photo 1 shows surface flow patterns in the tailrace with units 1, 2, and 3 operating with a total discharge of 24,500 cfs (8,166 cfs/unit), and a tailwater elevation of 23.1.* The fish attraction flow of 240 cfs was considered a normal operating condition for these tests. For the initial tests, a weir was not used in the fish entrances. The entrance was open from the fish slab elevation of 4.0 to the water surface. A circulating, low-velocity flow was present on the surface near the fish entrances. Surface flow increased along the left (looking downstream) training wall as the training wall intercepted the expanding flow from the boil at unit 3 and directed it downstream. Slack-water areas formed behind and immediately downstream of both training walls.

8. Velocity measurements recorded near the surface in the vicinity of the fish lift entrances and along the fish slab are shown in Plates 2 and 3. Return flow from the draft tube discharge caused upstream velocities in the vicinity of both fish entrances and dominated flow patterns in this area. It should be noted that all velocity measurements in this investigation are average velocities. Velocities 50 and 125 ft downstream from the fish entrances were in a downstream direction and higher than velocities at the fish entrances. Flow conditions in these areas were the result of the draft tube discharge at unit 3.

9. Tests were conducted with units 1 and 2 operating equally with a total discharge of 16,400 cfs, a tailwater elevation of 20.8, and fish attraction discharge of 240 cfs. These flow conditions are shown in Photo 2. With these conditions, flow exited the draft tubes and continued down the right half of the channel. Some of the flow from the draft tube boil at unit 2

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* All elevations (el) cited herein are in feet referred to the National Geodetic Vertical Datum (NGVD).

spread toward the left training wall (north wing wall) forming an eddy at the fish lift entrances and in the tailrace area downstream from unit 3. Smaller eddies were observed downstream in the shear zone formed from the draft tube discharge and upstream flow along the north (left) training wall. Approximately 1,000 ft downstream from the powerhouse, a slow upstream eddy was present along the left bank toward the powerhouse.

10. Velocity measurements obtained near the surface with the flow conditions shown in Photo 2 are shown in Plates 4 and 5. Velocities measured at the fish entrances were generally in a downstream direction, but were low. The velocities measured over the fish slab at distances of 50 and 125 ft downstream from the fish lift were all in an upstream direction and were less than 2.2 ft/sec.

11. Tests were then conducted with only unit 1 operating at a discharge of 8,200 cfs, a tailwater elevation of 16.6, and a fish attraction discharge of 240 cfs. With these conditions, flow exited the draft tubes and continued down the right side of the channel for approximately 1,000 ft, at which point an upstream eddy returned some of the flow along the left bank toward the powerhouse and along the left training wall all the way to the fish entrances. Photo 3 shows surface flow patterns for these conditions.

12. Velocities measured near the downstream fish entrance were generally in a downstream direction and higher than those observed with two and three units operating, as shown in Plates 6 and 7. However, the upstream flow from the large eddy caused the flow exiting the downstream fish entrance to circulate in a tight eddy between the fish lift entrance and the left training wall, and no velocities in a downstream direction were measured at distances of 50 and 125 ft downstream from the fish entrances. Velocities measured near the center of the upstream fish entrance were in a downstream direction.

Fish attraction flow of 500 cfs

13. To evaluate the effects of increased fish attraction flows, tests were conducted with all three units operating with the appropriate tailwater elevation and with 500 cfs discharging from the downstream fish entrance only. A 500-cfs discharge through the present system would need to be supplied from additional water sources other than the fish lift to prevent excessive turbulence, which would be harmful to fish in the system. The upstream fish entrance was closed for these tests. Surface flow patterns with all three units operating are shown in Photo 4. Because of the configuration of the

fish lift, the flow discharging from unit 3 separated at the downstream end of the fish lift, resulting in the formation of an eddy near the downstream fish entrance. The flow pattern resulting from unit 3 operating also forced the flow from the fish entrance against the left training wall.

14. Velocities measured with all three units operating and a fish attraction discharge of 500 cfs for the downstream entrance only are shown in Plates 8 and 9. The velocities measured near the center of the downstream fish entrance were greater than 3.8 ft/sec, which was considerably higher than those measured with a discharge of 240 cfs. Velocities 50 and 125 ft downstream from the fish lift entrance were comparable to those measured with a discharge of 240 cfs from the fish lift, indicating that the draft tube discharges dominate the flow patterns in these areas even with 500 cfs discharging from the fish lift entrance.

15. Surface flow patterns with units 1 and 2 operating and a fish attraction discharge of 500 cfs (Photo 5) indicate eddy patterns similar to those observed with a fish attraction discharge of 240 cfs (Photo 2). Velocities measured with units 1 and 2 operating and a discharge of 500 cfs are shown in Plates 10 and 11. Velocities greater than 4.5 ft/sec were measured near the center of the downstream fish entrance, but no velocities in the downstream direction were measured over the fish slab at distances of 50 and 125 ft downstream from the fish lift entrance. The surface flow patterns and velocity measurements indicate that an attraction flow of 500 cfs does not result in downstream flow along the left training wall with units 1 and 2 operating.

16. Surface flow patterns with unit 1 operating with a fish attraction discharge of 500 cfs are shown in Photo 6. Large eddies formed in the tailrace area downstream from units 2 and 3, and flow was observed in the downstream direction along the left training wall. Velocities measured along the fish slab are shown in Plates 12 and 13. Velocities measured near the center of the downstream fish entrance were as high as 8.4 ft/sec, and velocities were in the downstream direction 50 and 125 ft downstream from the fish entrance near the training wall. This type of flow pattern along the left training wall should be favorable for fish attraction; however, the velocities at the entrance may be too high for the fish to enter the lift.

17. Photos 7 and 8 show a close-up of flow conditions near the fish lift entrance with unit 1 operating at 8,200 cfs, a tailwater elevation of

16.6, and a fish attraction flow of 500 cfs. In Photo 7, only the downstream fish entrance is open, whereas in Photo 8 both entrances are open. Photo 7 shows the eddy downstream of the fish entrance to be less concentrated and further away from the training wall.

Modifications to the Fish Lift Entrances

18. The maximum flow that can presently be discharged through the original design fish lift entrances without excessive turbulence during the chamber filling operation is less than 240 cfs. The flow patterns and velocity measurements obtained during the initial tests indicated that a much greater discharge was needed to alter the circulation pattern in the tailrace and produce downstream flows along the left training wall with either unit 1 or units 1 and 2 operating. A discharge of 500 cfs from the fish lift produced flow in the downstream direction with only unit 1 operating. Testing efforts were therefore directed toward developing modifications that moved the entrances to the fish lift downstream to an area closer to the end of the left training wall. These wall extensions did not cause a measurable rise in the tailrace water-surface elevation or significantly increase velocities in the tailrace area.

19. All tests of modifications to the fish lift entrances were conducted with all three units operating equally at a powerhouse discharge of 21,300 cfs (7,100 cfs/unit) and a tailwater elevation of 26.0. Flow conditions similar to these are normally experienced at St. Stephen Powerhouse during the period of greatest fish migration. Therefore, the US Army Engineer District, Charleston, and the US Army Engineer Waterways Experiment Station (WES) agreed to use a discharge of 7,100 cfs/unit for the remainder of the testing program. Total fish attraction flow was 500 cfs, and flow through the fish entrances was controlled by a weir set at an elevation to produce an average velocity of 5 ft/sec exiting the entrance. It was decided in a meeting with personnel from the Charleston District, South Carolina Wildlife and Marine Resources Department (SCWMRD), and US Fish and Wildlife Service (USFWS) that an average velocity of 5 ft/sec exiting the fish entrance would be required for attraction flow. For these tests, as in previous tests, with the original design, the 500-cfs flow was supplied by a single pipe located far enough upstream from the fish entrances to allow for smooth flow in the

modified fish channel and entrance. Flow patterns were determined only at the new entrances and the areas downstream from these entrances.

Type 1 fish entrance modification

20. The type 1 entrance modification moved the downstream fish entrance approximately 130 ft downstream from its original location, as shown in Plate 14. This modification provided an 8-ft-wide entrance with attraction flow discharging along the north wing wall in a downstream direction. The top of the entrance weir was at el 13.5. Velocity measurements with the type 1 entrance modification are shown in Plates 15 and 16. These velocities indicated that flow in a downstream direction existed along the training wall throughout the depth of flow and increased in magnitude near the surface. The initial concept to attract fish was to provide an avenue of flow with a velocity higher than that of the tailrace flow from the powerhouse discharge. The type 1 entrance modification did not provide these higher velocities.

Types 2, 3, and 4 fish entrance modifications

21. Types 2, 3, and 4 entrance modification concepts, shown in Plates 17-19, were developed in a meeting between the Charleston District and WES personnel. Since the type 2 and 3 modifications were similar to the type 1 entrance modification, they were not tested because of the performance of the type 1 entrance modification. Since the type 4 entrance modification would require considerable excavation, it was decided to test methods that did not require additional excavation.

Type 5 fish entrance modification

22. The type 5 entrance modification consisted of an 8-ft-wide fish entrance located approximately 215 ft downstream from the original entrances, as shown in Plate 20. The top of the entrance weir was at el 13.5. This modification provided downstream attraction flow in the vicinity of the eddy area near the end of the north wing wall. Velocity measurements, shown in Plates 21 and 22, indicated that surface velocities downstream from the fish entrance were higher than the velocity of the tailrace flow.

Type 6 fish entrance modification

23. The type 6 entrance modification (Plate 23) was tested to determine the effect of directing attraction flow more toward the center of the tailrace channel, but otherwise was identical to the type 5 entrance modification. Velocity magnitudes (Plates 24 and 25) were similar to those measured with the type 5 entrance modification in place, but flow patterns differed slightly.

because of the angle of the flow directed from the fish entrance. The entrance weir elevation was at 13.5. Velocities along the left bank were lower with the type 6 entrance modification.

Type 7 fish entrance modification

24. The type 7 entrance modification, shown in Plate 26, consisted of two fish entrances. The upstream entrance was 6 ft wide and located at the downstream end of the present north wing wall. The top of the entrance weir was at el 19.3. Approximately 40 percent of the fish attraction flow (200 cfs) discharged from this entrance. Attraction flow was released toward the left bank of the tailrace channel. The downstream fish entrance was 8 ft wide and located 25 ft from the end of the north wing wall. The top of the entrance weir was at el 18.5. Approximately 60 percent (300 cfs) of fish attraction flow discharged from this entrance. This modification provided attraction flow directly to the eddy area behind the north wing wall through the 6-ft-wide entrance. Velocities with the type 7 entrance modification are shown in Plates 27 and 28. The surface velocities on the left bank could be excessive for the existing bank protection.

Types 8, 9, and 10 fish entrance modifications

25. Further testing consisted of installing various types of wall extensions to cut off eddy areas behind and downstream of both tailrace wing walls. These walls were used as additions to the types 8, 9, and 10 entrance modifications. These modifications were designed to provide downstream flow along a wall to at least one fish entrance. It was decided in the previously mentioned meeting with the Charleston District, SCWMRD, and USFWS that downstream flow along a wall leading to a fish entrance was an important design feature even when velocities along the wall were lower than the velocity of the tailrace flow from the powerhouse units.

26. The type 8 entrance modification (Plate 29) was a refined version of the type 1 entrance modification. The downstream fish entrance was extended approximately 88 ft downstream to a point just beyond the area in the tailrace where the flow from the boil caused by the unit 3 discharge travels in a downstream direction along the north training wall. This modification provided flow along the training wall and could also be beneficial to fish traveling up the right side of the channel and across the tailrace. The top of the entrance weir was at el 13.5. Velocities measured with the type 8 entrance modification are shown in Plates 30 and 31. Photo 9 shows the

surface flow conditions with the type 8 entrance modification in place. Flow patterns and velocities measured at various depths inside the north wing wall were in a downstream direction.

27. There was concern that fish might remain in the low-velocity circulating flow behind the north wing wall. A wall was installed from the end of the north wing wall to the left bank, shown in Plate 32. Surface velocities with the type 8 entrance modification in place and the wall blocking off the eddy area behind the north wing wall are also shown in Plate 32. This type wall caused only slight changes in the flow patterns, and velocity magnitudes were the same as without the wall. The eddy area was still present downstream from the wing wall.

28. The north wing wall was extended 300 ft downstream to the left berm with the top of the wall extension at el 26. Photo 10 shows surface flow patterns with the type 8 entrance modification and the wall extension in place. This extension to the north wing wall prevented the eddies from developing behind and downstream of the original wing wall, as can be seen by comparing Photos 9 and 10. Flow along the wall extension was in a downstream direction.

29. The type 9 entrance modification (Plate 33) provided two fish entrances. The upstream entrance was 8 ft wide and located approximately 88 ft downstream from the present fish entrances. Approximately 380 cfs or 76 percent of the fish attraction flow passed through this entrance. The top of the entrance weir was at el 16. The downstream entrance was 6 ft wide and located approximately 130 ft downstream of the present entrances at the bend of the north wing wall. Attraction flow through this entrance was approximately 120 cfs or 24 percent of the total attraction flow, and the top of the fish entrance weir was set at el 21. Plates 34 and 35 show velocity measurements with the type 9 entrance modification, and Photo 11 shows surface flow conditions with this modification in place. This modification provided downstream flow along training walls leading to both fish entrances.

30. To investigate the effect of preventing the low-velocity eddy from developing behind both the north wing wall and the south training wall, the wall modifications shown in Plate 36 were tested. The north wing wall extension was the same as tested with the type 8 entrance modification. The south training wall was extended 337.5 ft downstream and a wing wall 195 ft long was angled to the top of the right bank berm at el 26. The extension to the south

training wall eliminated a large eddy and slack-water area that formed behind the original training wall and down the right bank of the tailrace canal. The extension to the north wing wall eliminated the eddy along the left bank previously observed with the type 8 entrance modification in place. Flow conditions with the type 9 entrance modification and the wall modifications to both the north wing wall and south training wall are shown in Photo 12. The tailwater elevation was lowered to 24.25 to prevent overtopping of the south wing wall. No eddies were observed with this flow condition.

31. The extension on the south wing wall was removed to observe flow conditions in the tailrace area with the type 9 entrance modification and the north wing wall extension in place. As seen in Photo 13, the wing wall extension eliminated the eddy from forming along the left bank. However, eddies did develop behind the south training wall and along the right bank.

32. In the type 10 entrance modification (Plate 37), the 6-ft-wide fish entrance in the type 9 entrance modification was moved to the end of the north wing wall in an attempt to provide attraction flows in the vicinity of the downstream end of the wing wall. This entrance was approximately 215 ft downstream from the present fish entrances. The weir elevation was the same as with the type 9 entrance modification and the flow distribution through the entrances was approximately the same. The type 10 entrance modification combined the features from the type 8 and type 5 entrance modifications. The 6-ft-wide downstream entrance supplied fish attraction flow in the vicinity of the eddy area behind and downstream from the north wing wall. The 8-ft-wide upstream entrance may be helpful in intercepting migrating fish that move upstream along the south side of the channel and cross over to the north side of the tailrace canal. Velocity measurements with type 10 entrance modification in place are shown in Plates 38 and 39.

33. Photo 14 shows flow conditions for the type 10 entrance modification with and without wing wall additions. The north wing wall additions did prevent the eddy from forming behind the wing wall; however, an eddy still formed downstream along the left bank. Photo 15 shows surface flow conditions with the type 10 entrance modification in place and the 300-ft extension to the north wing wall. As in previous tests with the type 9 entrance modification (Photo 13), flow was trained in a downstream direction along the wall, eliminating eddies along this portion of the left bank of the tailrace canal.

PART IV: CONCLUSIONS AND RECOMMENDATIONS

34. The flow patterns and velocity measurements recorded during initial tests indicated a discharge of at least 500 cfs through the original design fish entrances was needed to produce desired flow conditions for fish attraction. A 500-cfs discharge through the present fish lift system would create excessive turbulence during the chamber filling operation resulting in harm to the fish within the system.

35. Tests were conducted with wall extensions along the fish slab to move fish lift entrances to areas where flow would discharge through the entrances and continue in a downstream direction. These tests were conducted with the three turbine units operating at equal discharges. The recommended discharges through the fish entrances for these modifications was 500 cfs. Flow at the fish entrances was controlled by a weir set at an elevation to produce an average velocity of 5 ft/sec. These modifications to the fish lift entrances varied the locations of the entrances (a distance of 88 ft to 240 ft) downstream of the original design entrances. Some modifications provided one entrance (types 1, 3, 5, 6, and 8), while others were designed with two entrances (types 2, 4, 7, 9, and 10).

36. Wall extensions to the existing wing walls were placed in the model to eliminate dead areas and eddies along the left and right banks downstream of and behind existing walls. These walls trained the flow from the powerhouse and fish entrances in a downstream direction. A wall from the end of the north wing wall to a point approximately perpendicular to the left bank was tested to eliminate the eddy area behind the north wing wall. This type wall extension only relocated the eddy to an area just downstream of the new wall.

37. The wall additions to the fish slab did not adversely affect hydraulic conditions in the tailrace area. There was no significantly measurable increase in water-surface elevations downstream of the draft tube outlets. Velocity magnitudes and distribution were also approximately the same over the tailrace slab and downstream riprap protection.

38. The recommended design for improving fish attraction capabilities is the type 9 entrance modification. This modification provided for two fish entrances. The upstream entrance was located approximately 88 ft downstream of the present fish entrances. This placed the upstream entrance as close to

the powerhouse as possible, yet at a point far enough downstream where the boil from unit 3 discharge would not adversely affect flow conditions at the entrance. This entrance could also be beneficial in intercepting fish that move across from the south side of the tailrace. The downstream entrance of the type 9 entrance modification was located approximately 130 ft downstream of the present entrances at the bend of the north wing wall. This provided an entrance in an area of lower velocity than the upstream entrance and would benefit species of fish that prefer slower, less turbulent flow. Downstream flow along walls leading to both entrances was provided in the type 9 entrance modification.

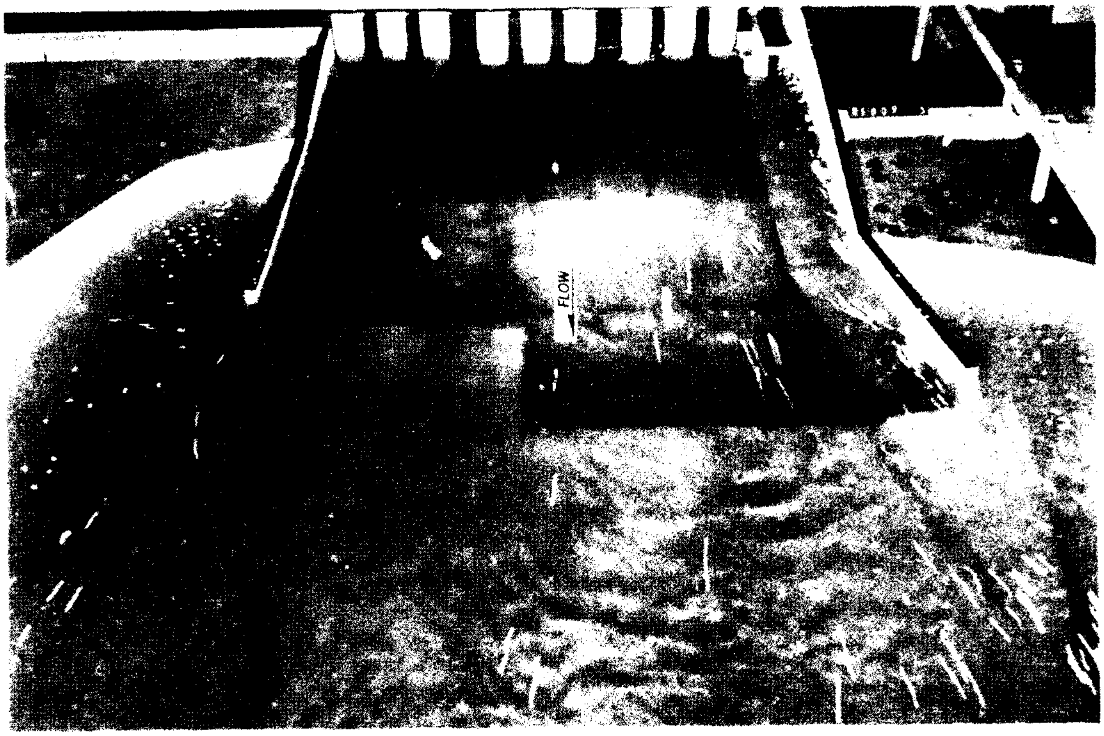


Photo 1. Surface flow patterns, original design, discharge 24,500 cfs, tailwater el 23.1, fish attraction flow 240 cfs, units 1, 2, and 3 operating

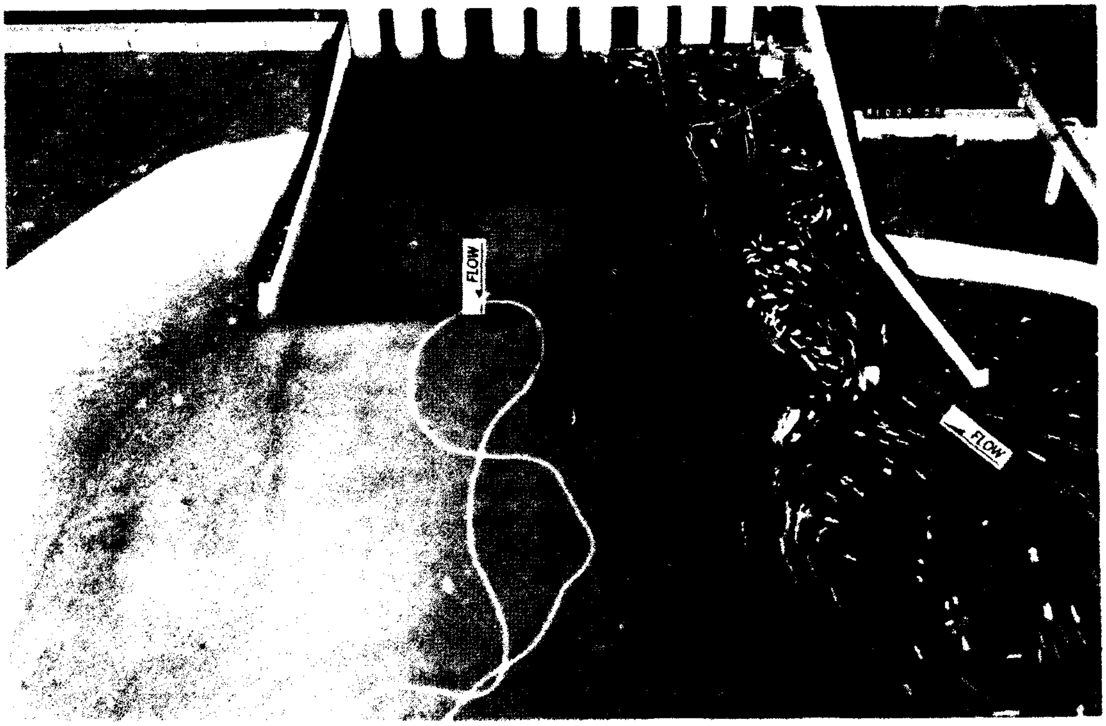


Photo 2. Surface flow patterns, original design, discharge 16,400 cfs, tailwater el 20.8, fish attraction flow 240 cfs, units 1 and 2 operating

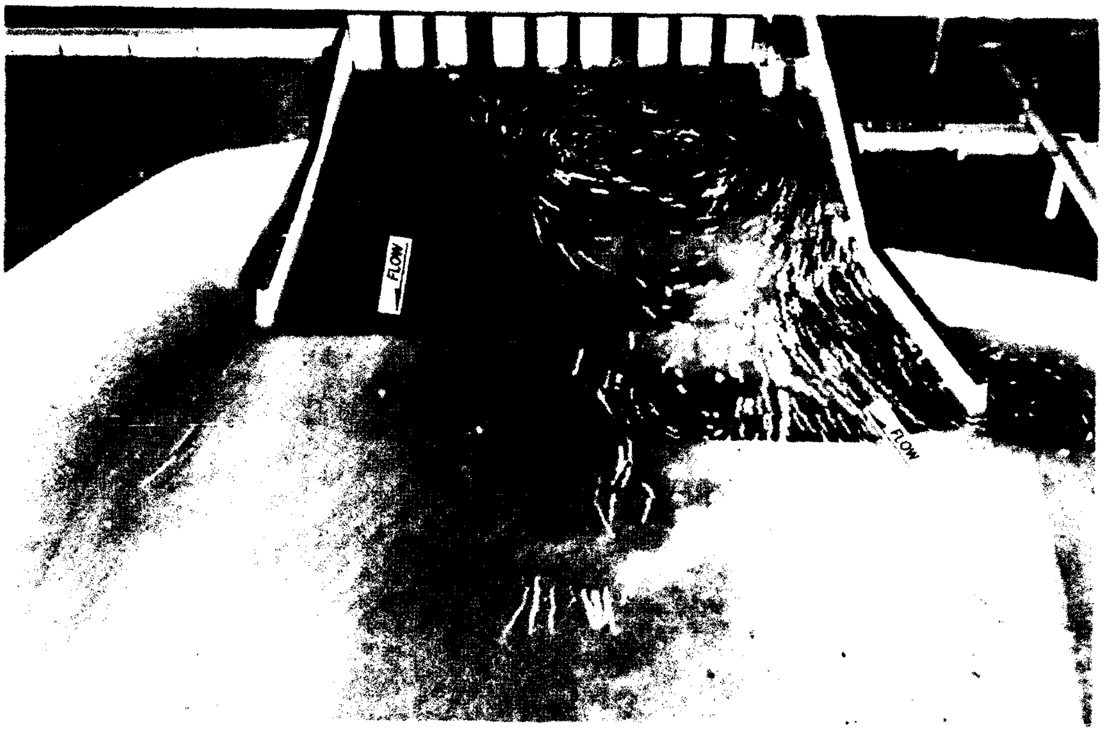


Photo 3. Surface flow patterns, original design, discharge 8,200 cfs, tailwater el 16.6, fish attraction flow 240 cfs, unit 1 operating

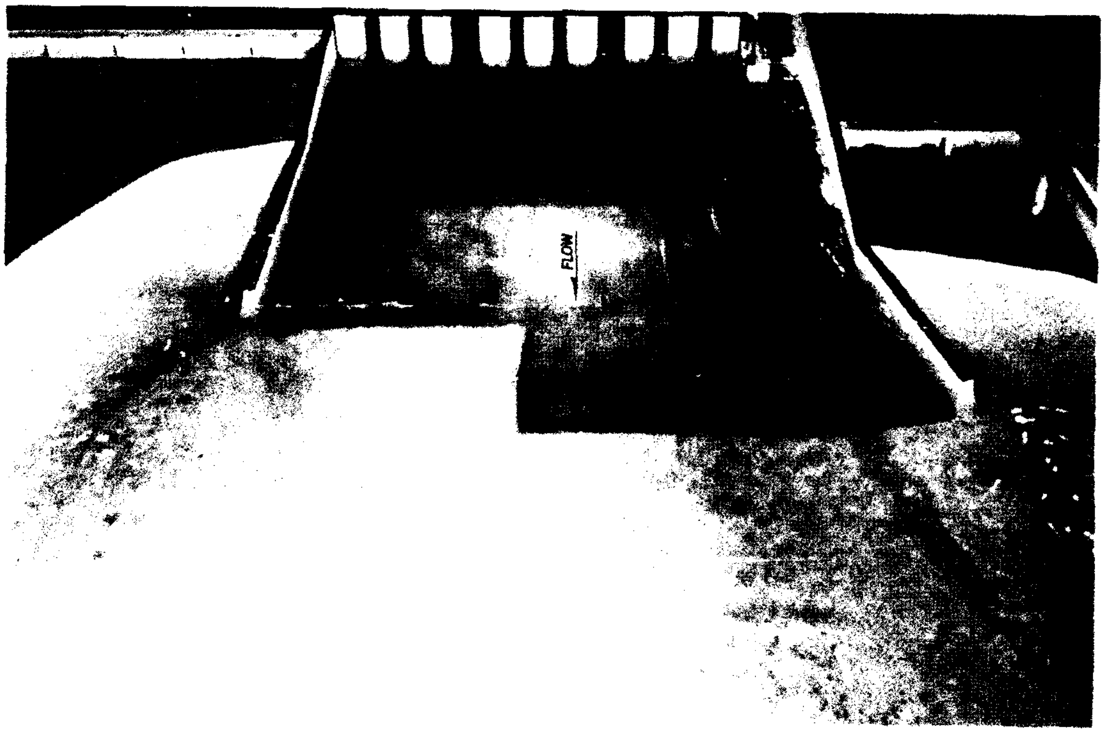


Photo 4. Surface flow patterns, original design, discharge 24,500 cfs, tailwater el 23.1, fish attraction flow 500 cfs (downstream fish entrance only), units 1, 2, and 3 operating

Photo 5. Surface flow patterns, original design, discharge 16,400 cfs, tailwater el 20.8, fish attraction flow 500 cfs (downstream fish entrance only), units 1 and 2 operating

Photo 6. Surface flow patterns, original design, discharge 8,200 cfs, tailwater el 16.6, fish attraction flow 500 cfs (downstream fish entrance only), unit 1 operating

Photo 7. Close-up view of surface flow patterns, original design, discharge 8,200 cfs, tailwater el 16.6, fish attraction flow 500 cfs (downstream fish entrance only), unit 1 operating

Photo 8. Close-up view of surface flow patterns, original design, discharge 8,200 cfs, tailwater el 16.6, fish attraction flow 500 cfs (both fish entrances open), unit 1 operating

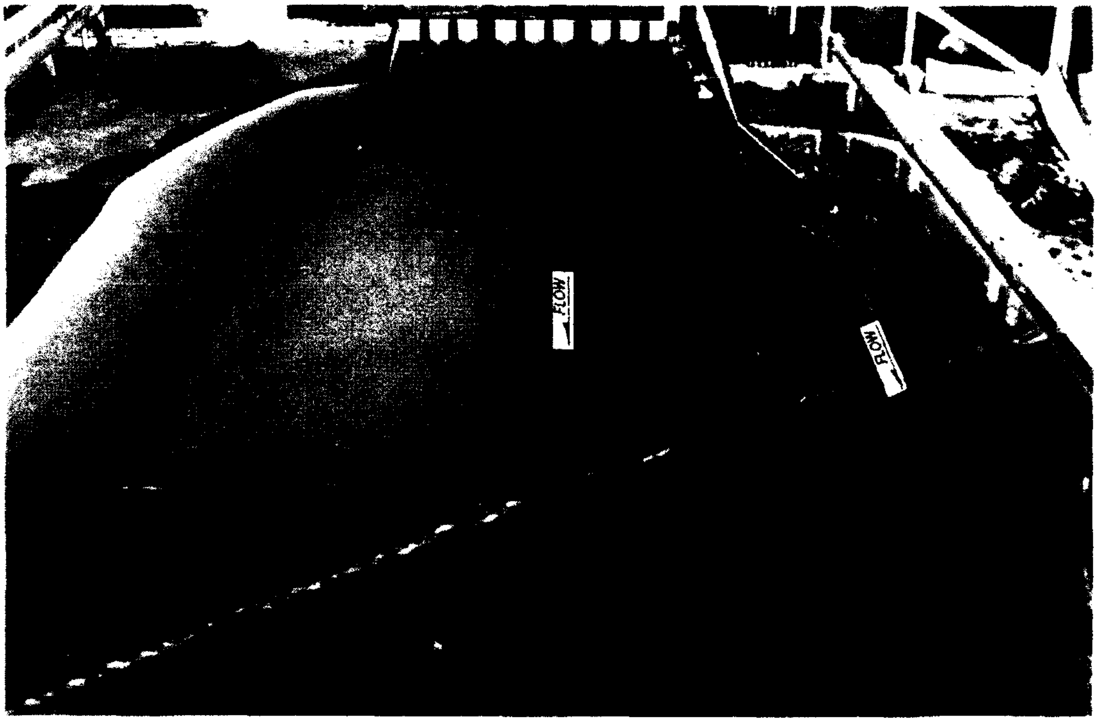


Photo 9. Surface flow patterns, type 8 entrance modification, discharge 7,100 cfs per unit, tailwater el 26.0, fish attraction flow 500 cfs, units 1, 2, and 3 operating

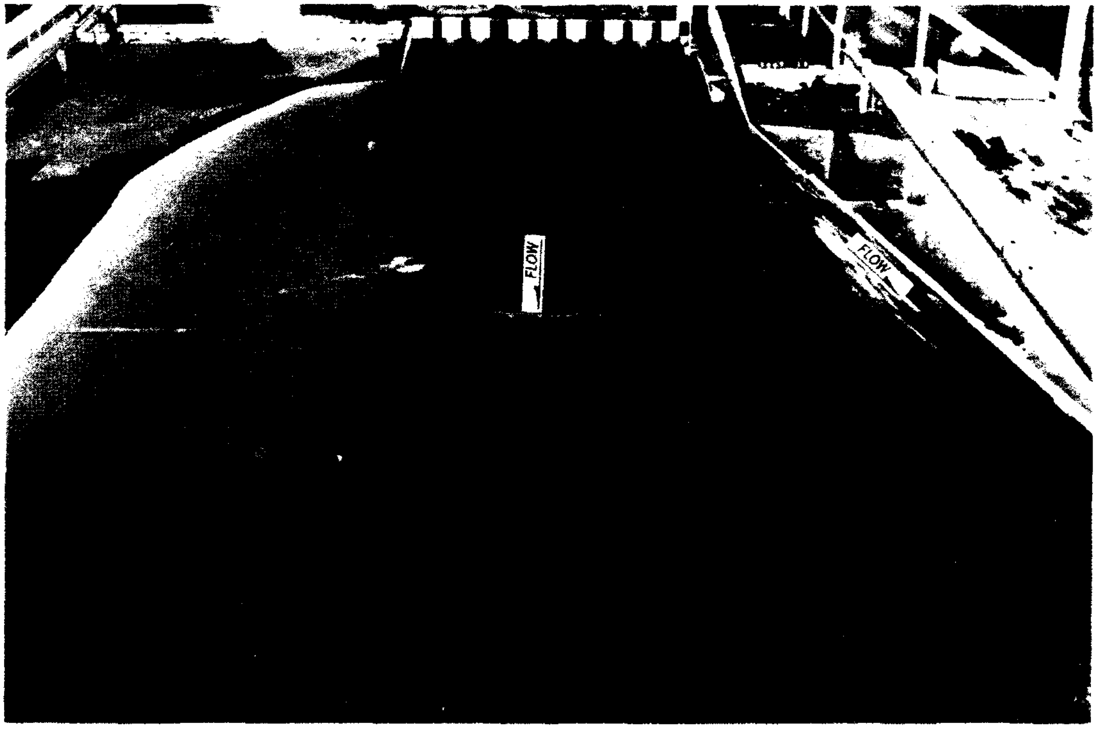


Photo 10. Surface flow patterns, type 8 entrance modification, north wing wall extended 300 ft, discharge 7,100 cfs per unit, tailwater el 26.0, fish attraction flow 500 cfs, units 1, 2, and 3 operating

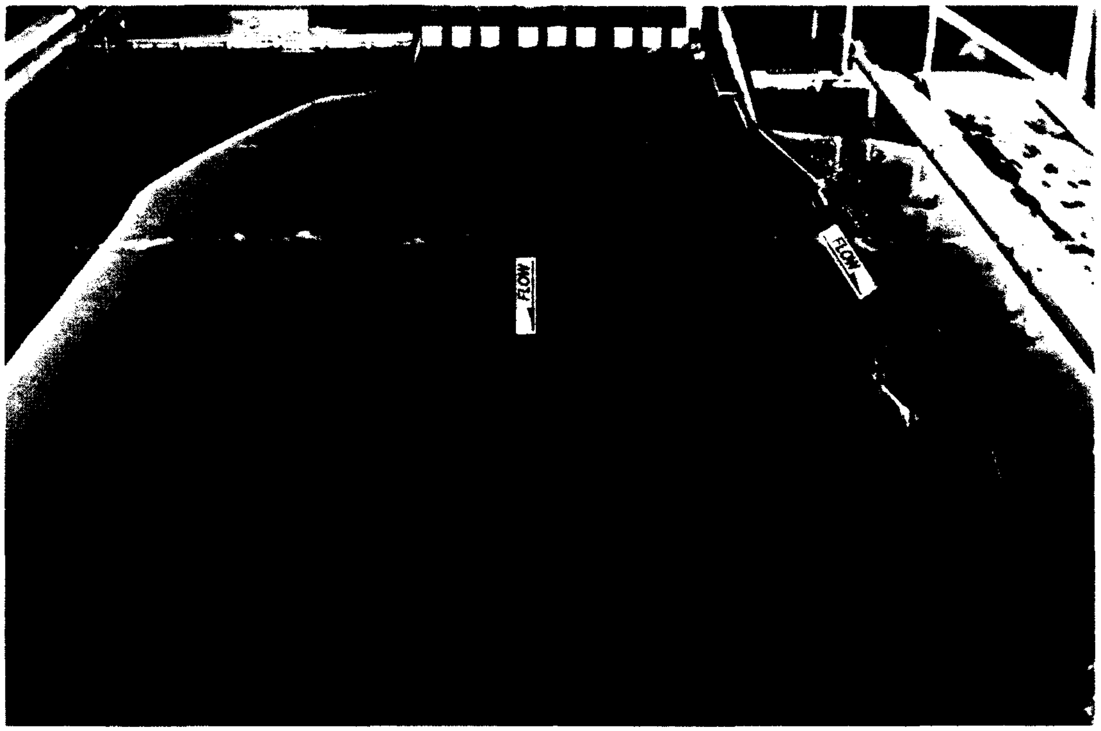


Photo 11. Surface flow patterns, type 9 entrance modification, discharge 7,100 cfs per unit, tailwater el 26.0, fish attraction flow 500 cfs, units 1, 2, and 3 operating

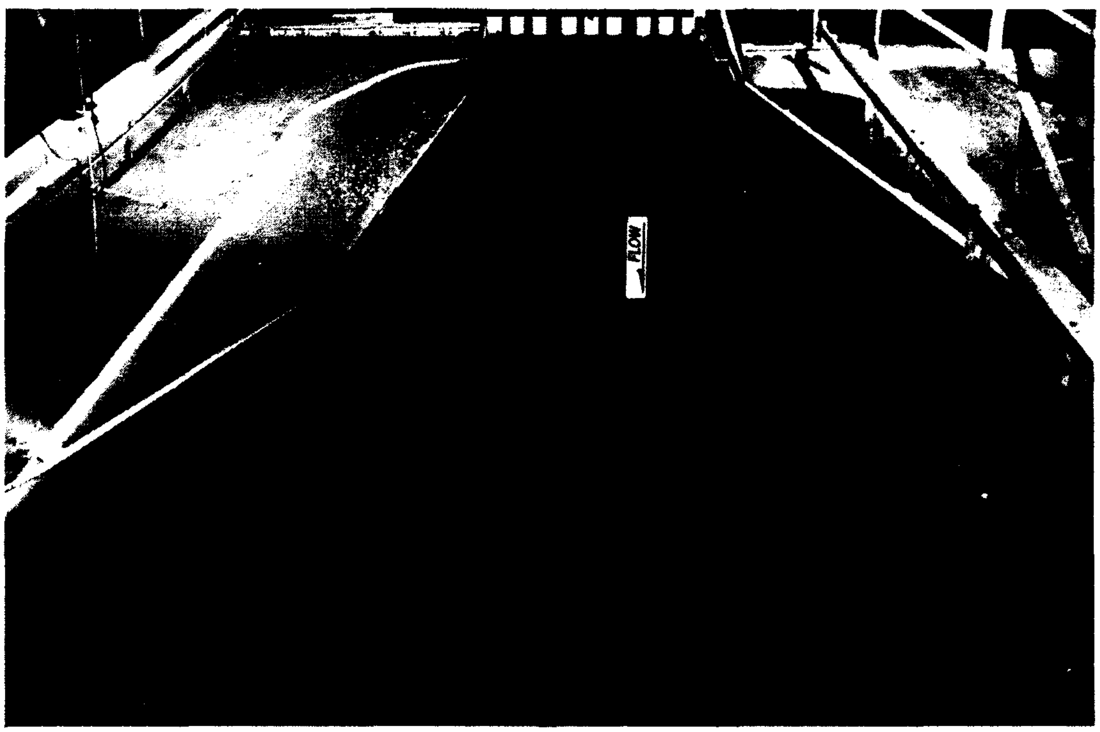


Photo 12. Surface flow patterns, type 9 entrance modification, north and south wing walls extended, discharge 7,100 cfs per unit, tailwater el 24.25, fish attraction flow 500 cfs, units 1, 2, and 3 operating

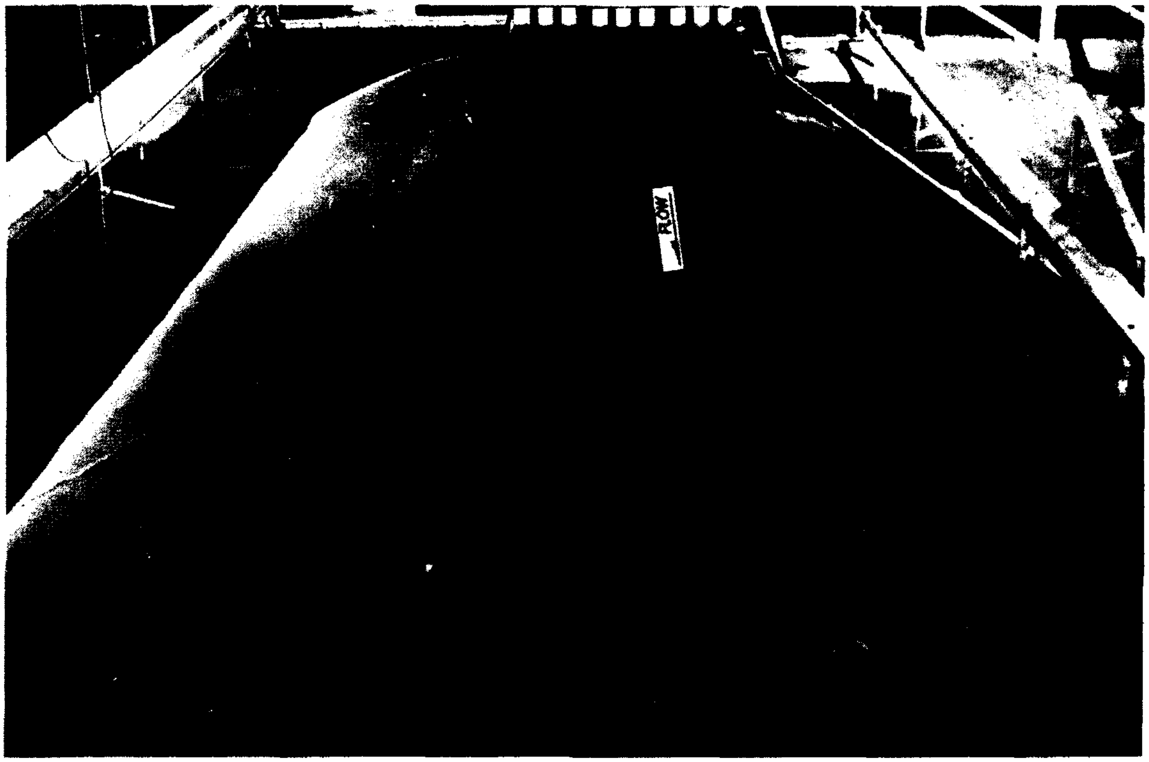
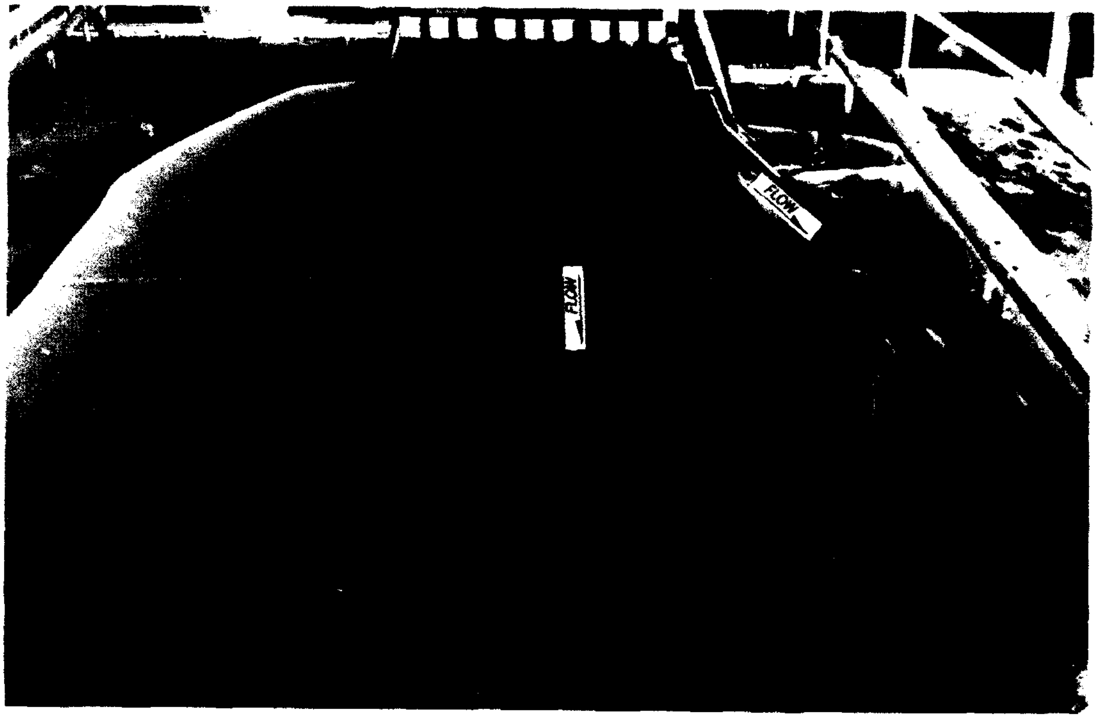
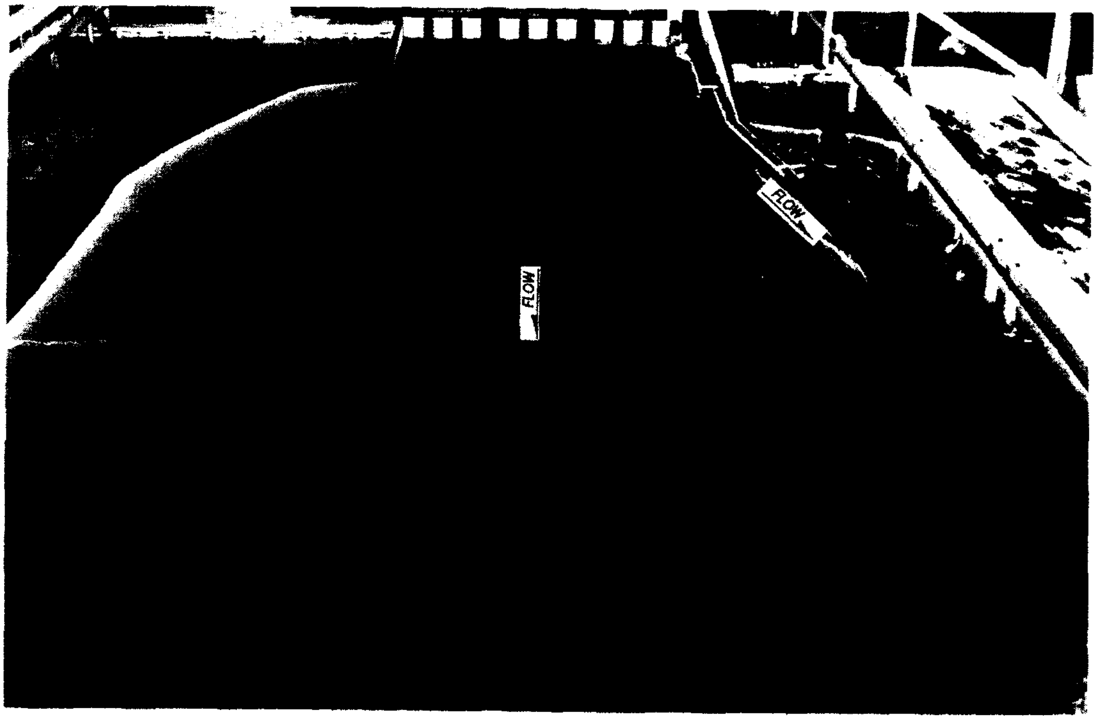


Photo 13. Surface flow patterns, type 9 entrance modification, north wing wall extended 300 ft, discharge 7,100 cfs per unit, tailwater el 26.0, fish attraction flow 500 cfs, units 1, 2, and 3 operating



a. With wing wall addition



b. Without wing wall addition

Photo 14. Surface flow patterns, type 10 entrance modification, with and without north wing wall extension, discharge 7,100 cfs per unit, tailwater el 26.0, fish attraction flow 500 cfs, units 1, 2, and 3 operating

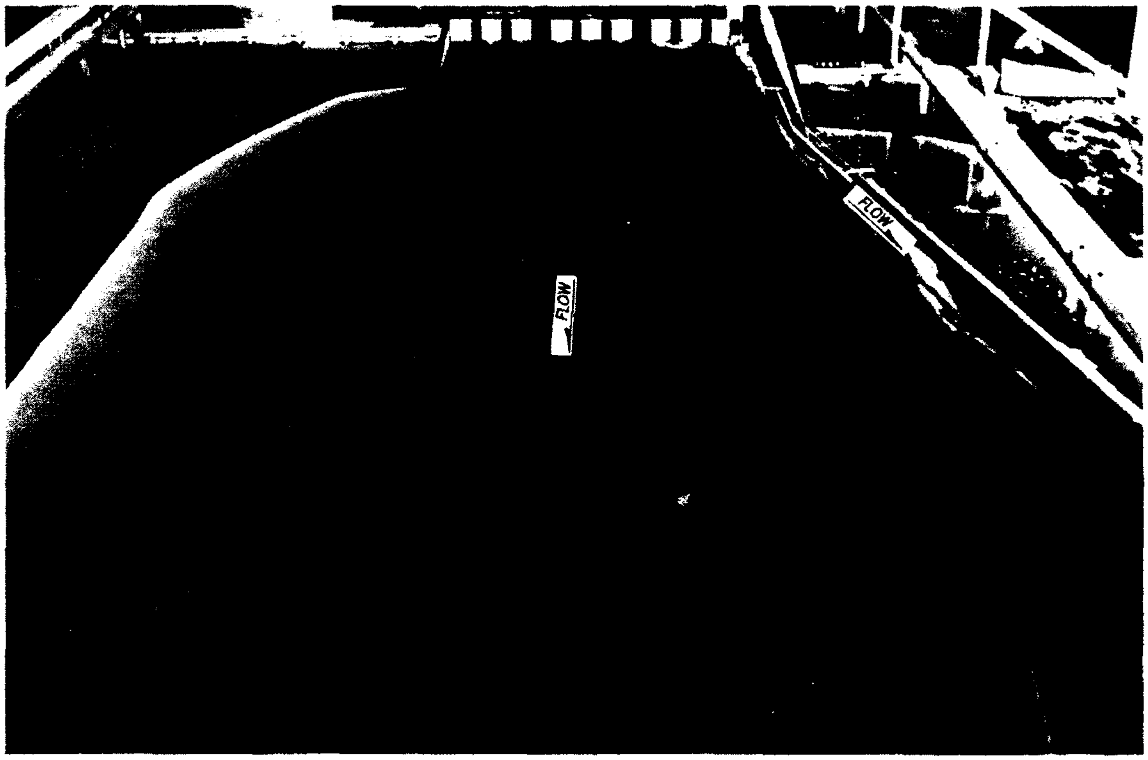
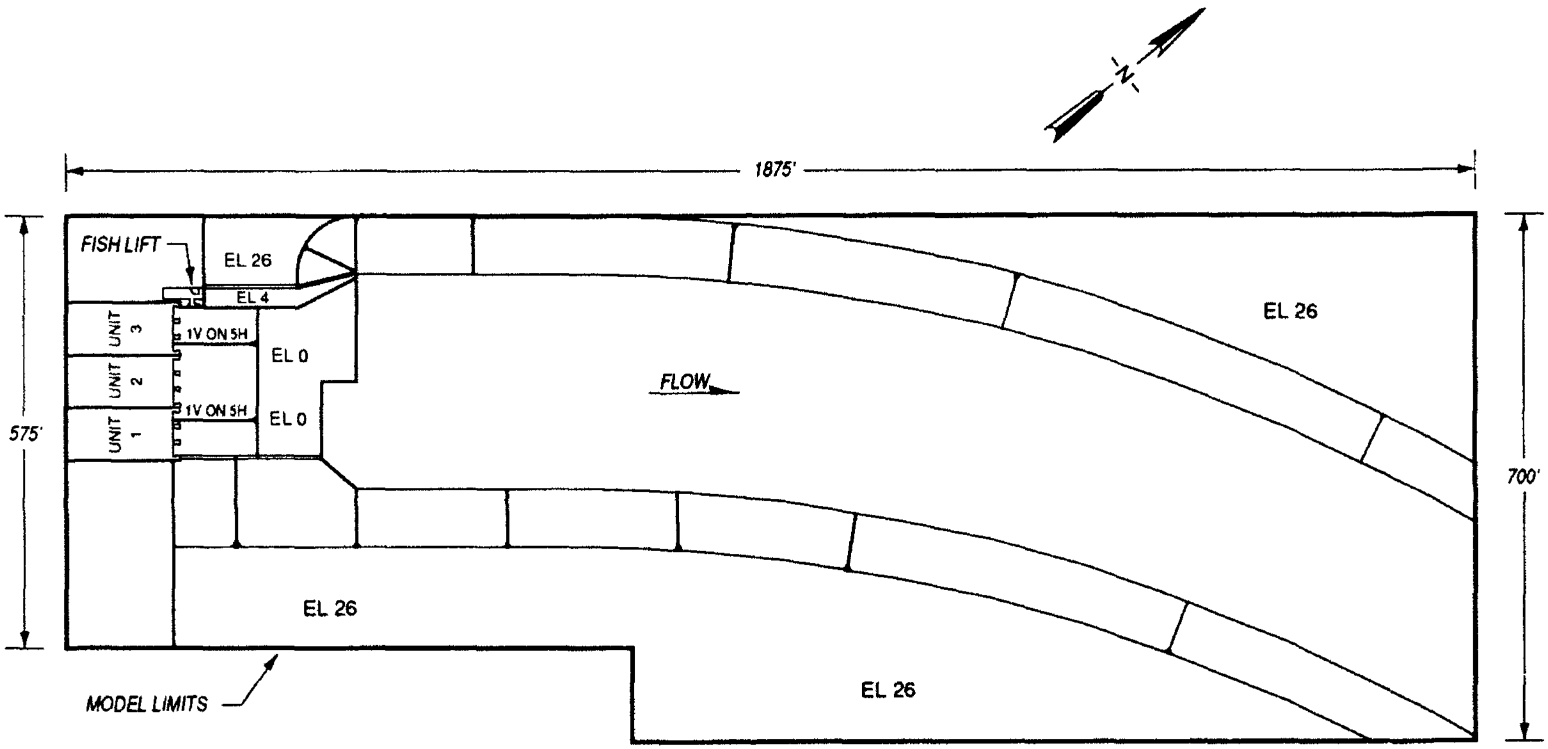
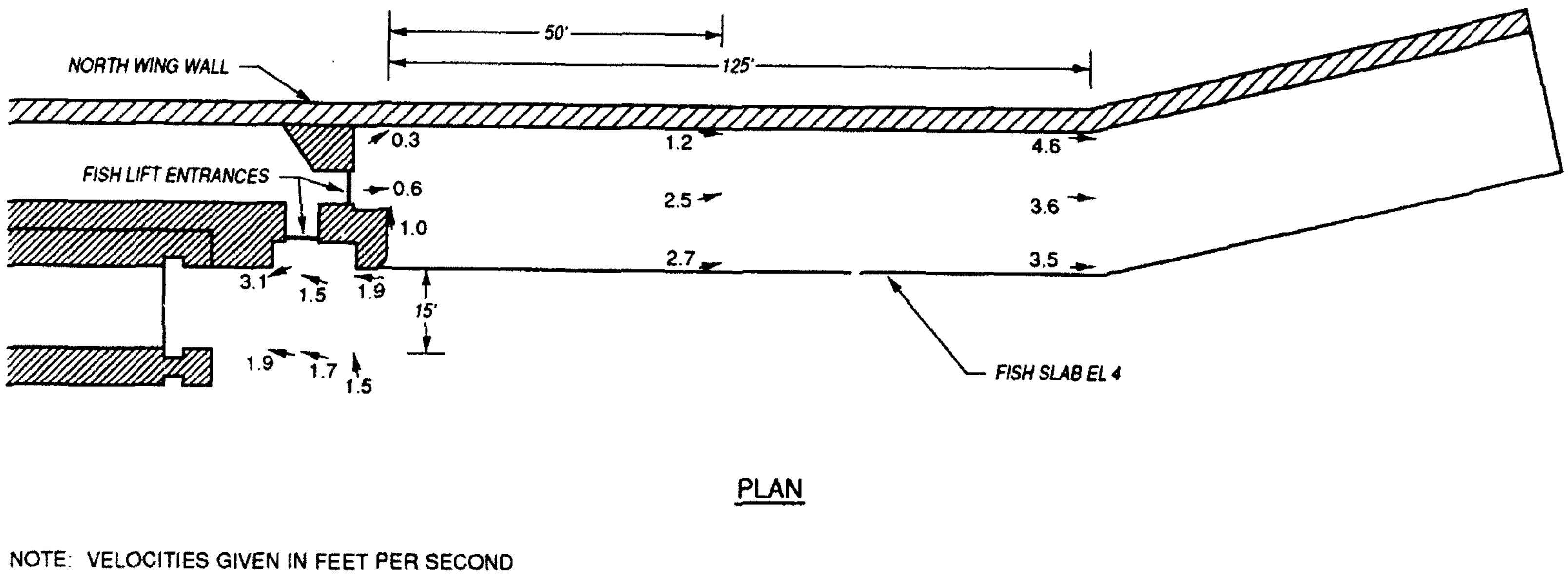


Photo 15. Surface flow patterns, type 10 entrance modification, north wing wall extended 300 ft, discharge 7,100 cfs per unit, tailwater el 26.0, fish attraction flow 500 cfs, units 1, 2, and 3 operating

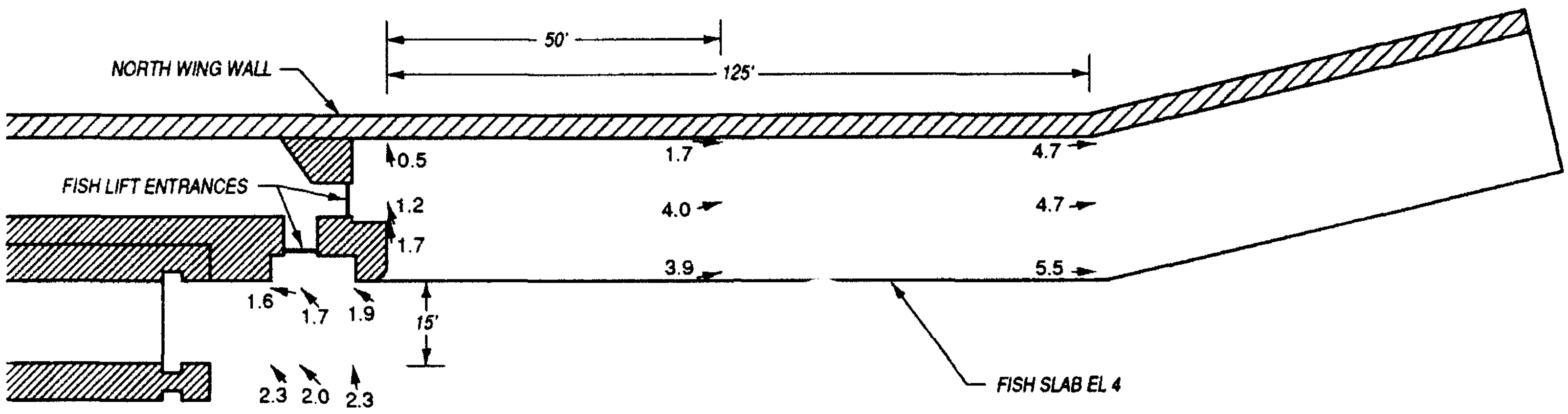


PLAN

MODEL LAYOUT OF
ORIGINAL DESIGN



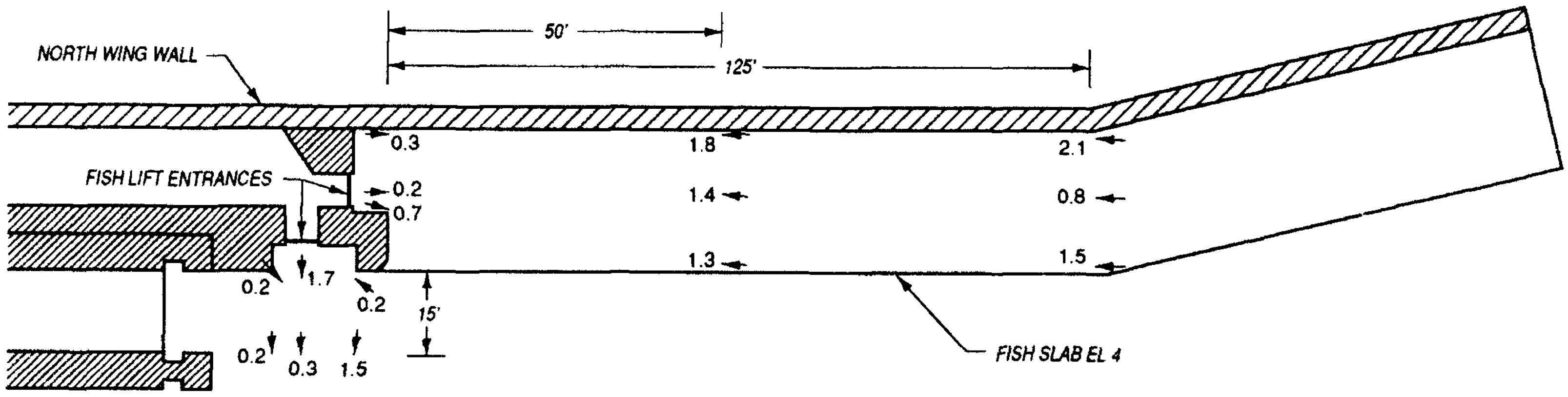
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 24,500 CFS, UNITS 1,2,3 OPERATING
FISH ATTRACTION FLOW 240 CFS
TAILWATER EL 23.1
VELOCITIES MEASURED AT EL 15



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

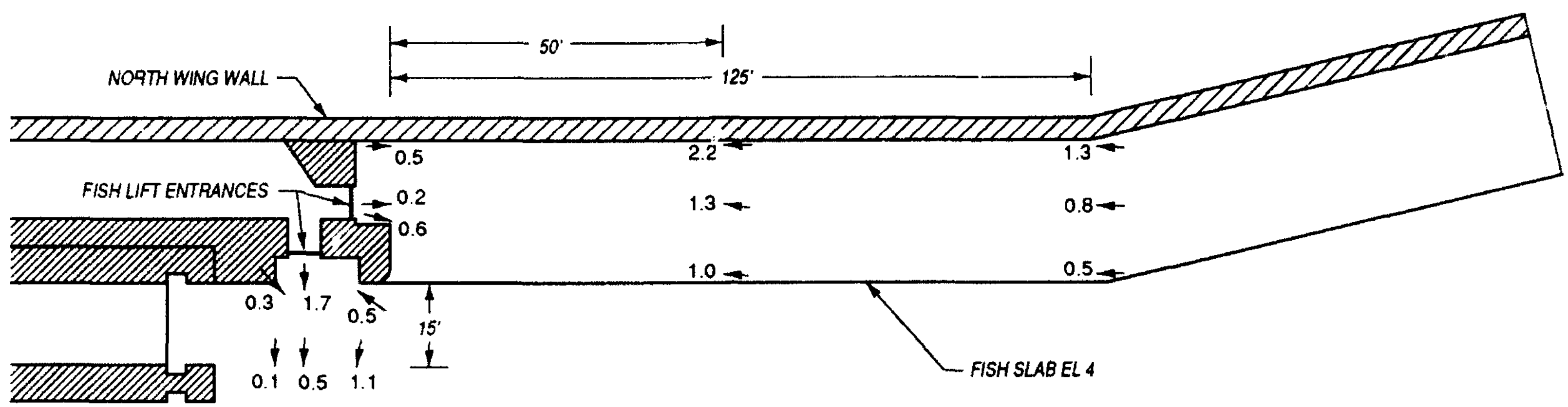
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 24,500 CFS, UNITS 1,2,3 OPERATING
FISH ATTRACTION FLOW 240 CFS
TAILWATER EL 23.1
VELOCITIES MEASURED AT EL 22



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

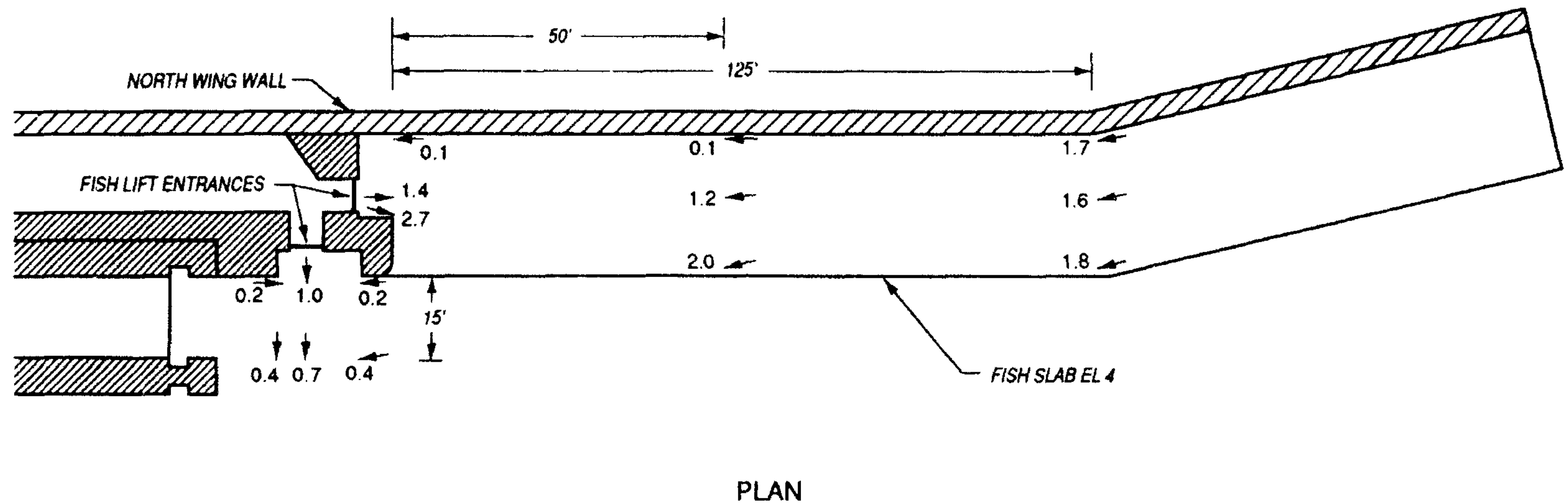
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 16,400 CFS, UNITS 1,2 OPERATING
FISH ATTRACTION FLOW 240 CFS
TAILWATER EL 20.8
VELOCITIES MEASURED AT EL 15



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

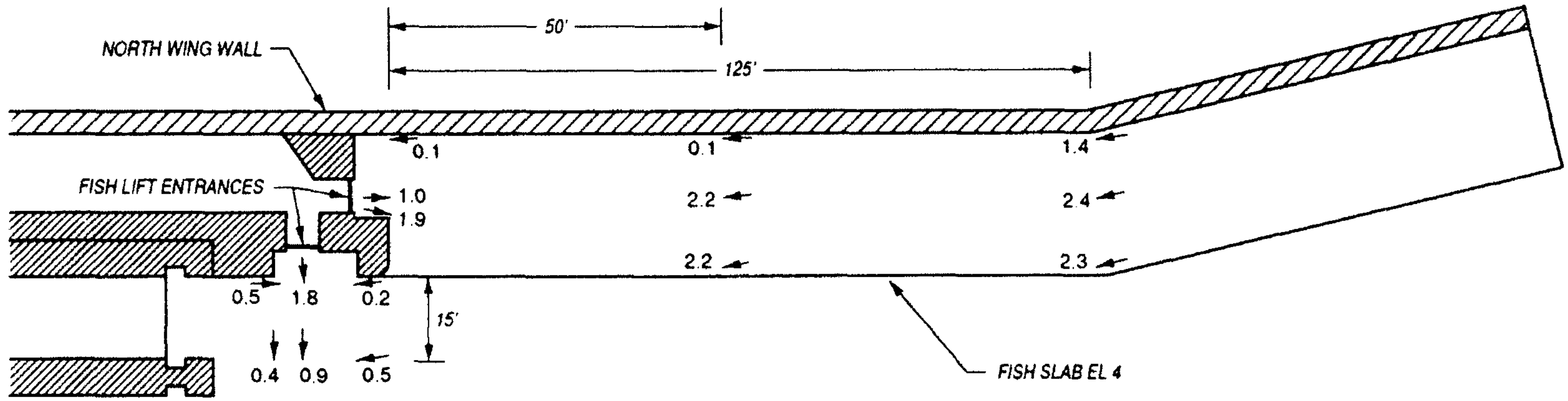
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 16,400 CFS, UNITS 1,2 OPERATING
FISH ATTRACTION FLOW 240 CFS
TAILWATER EL 20.8
VELOCITIES MEASURED AT EL 19



NOTE: VELOCITIES GIVEN IN FEET PER SECOND

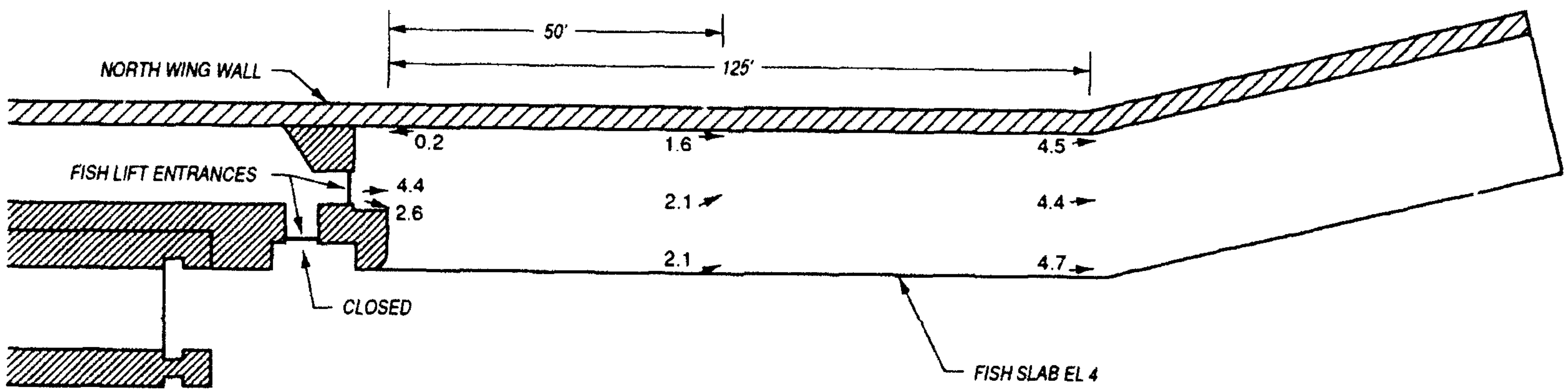
VELOCITIES NEAR FISH LIFT

ORIGINAL DESIGN
DISCHARGE 8,200 CFS, UNIT 1 OPERATING
FISH ATTRACTION FLOW 240 CFS
TAILWATER EL 16.6
VELOCITIES MEASURED AT EL 10



NOTE: VELOCITIES GIVEN IN FEET PER SECOND

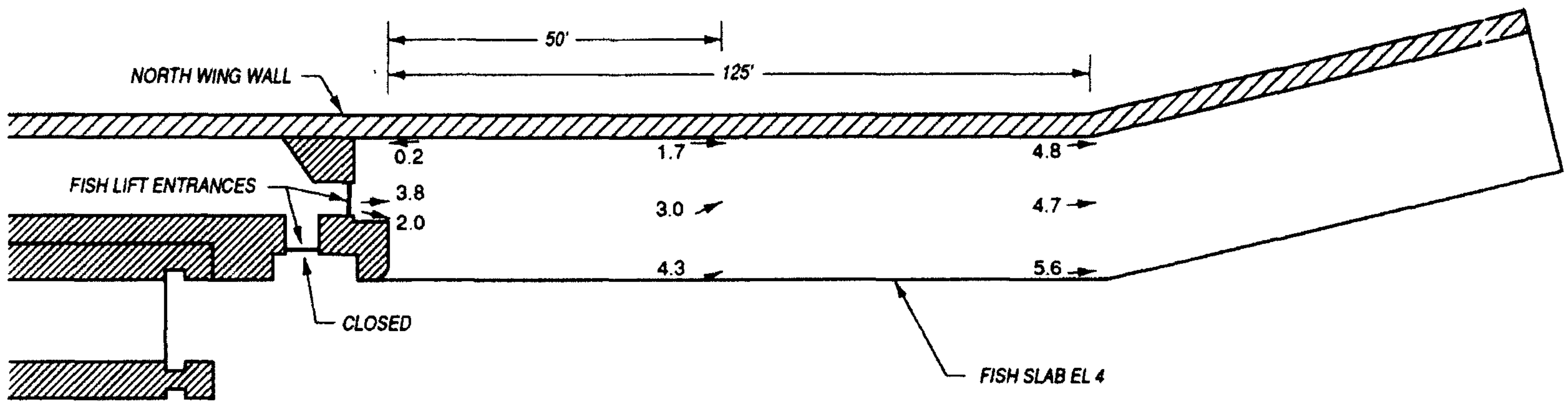
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 8,200 CFS, UNIT 1 OPERATING
FISH ATTRACTION FLOW 240 CFS
TAILWATER EL 16.6
VELOCITIES MEASURED AT EL 15 5



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

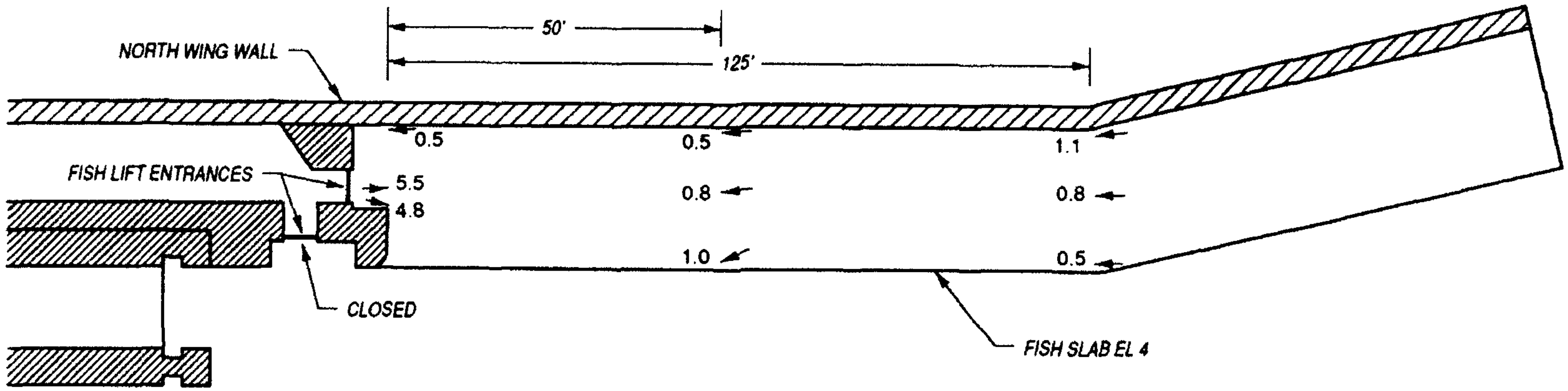
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 24,500 CFS, UNITS 1,2,3 OPERATING
FISH ATTRACTION FLOW 500 CFS
TAILWATER EL 23.1
VELOCITIES MEASURED AT EL 15



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

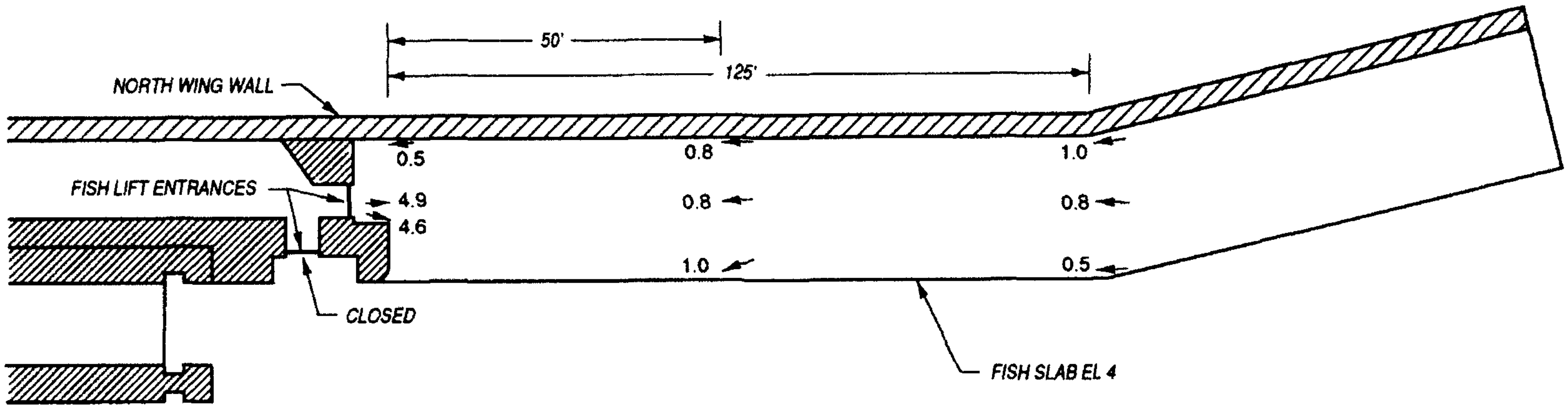
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 24,500 CFS, UNITS 1,2,3 OPERATING
FISH ATTRACTION FLOW 500 CFS
TAILWATER EL 23.1
VELOCITIES MEASURED AT EL 22



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

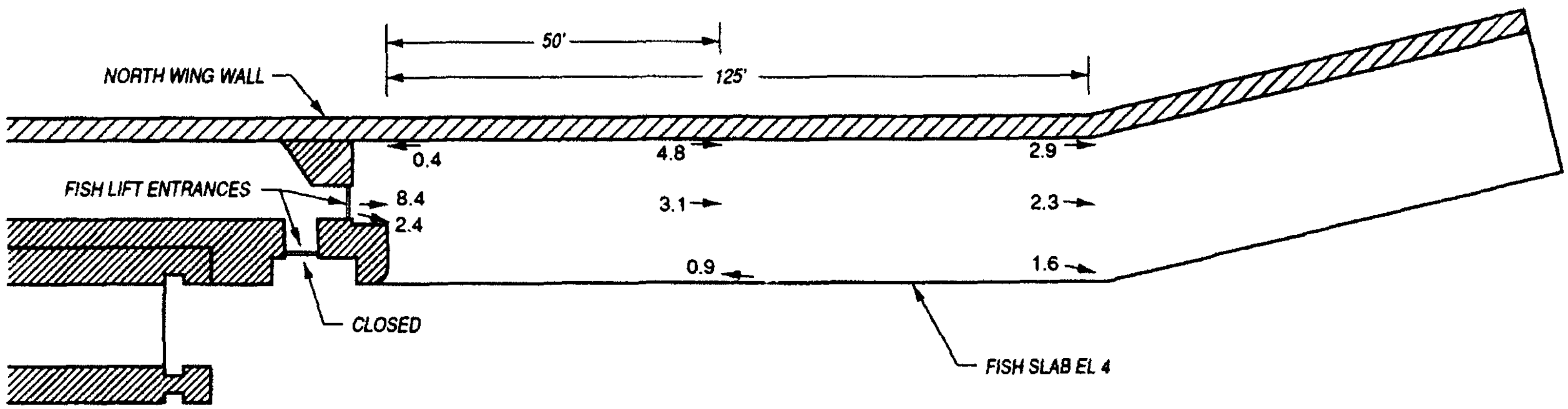
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 16,400 CFS, UNITS 1,2 OPERATING
FISH ATTRACTION FLOW 500 CFS
TAILWATER EL 20.8
VELOCITIES MEASURED AT EL 15



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

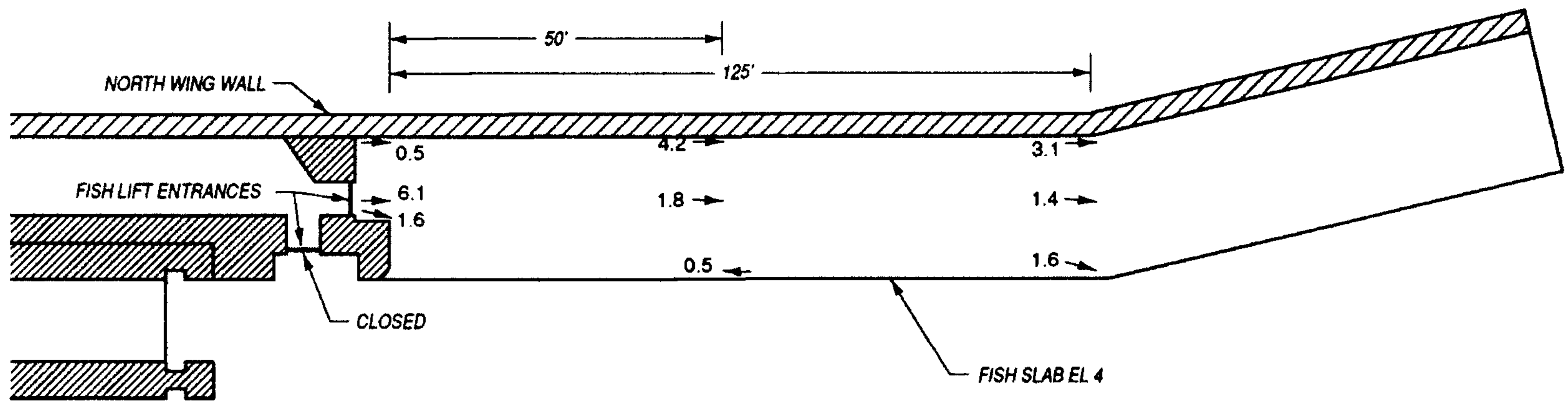
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 16,400 CFS, UNITS 1,2 OPERATING
FISH ATTRACTION FLOW 500 CFS
TAILWATER EL 20.8
VELOCITIES MEASURED AT EL 19



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

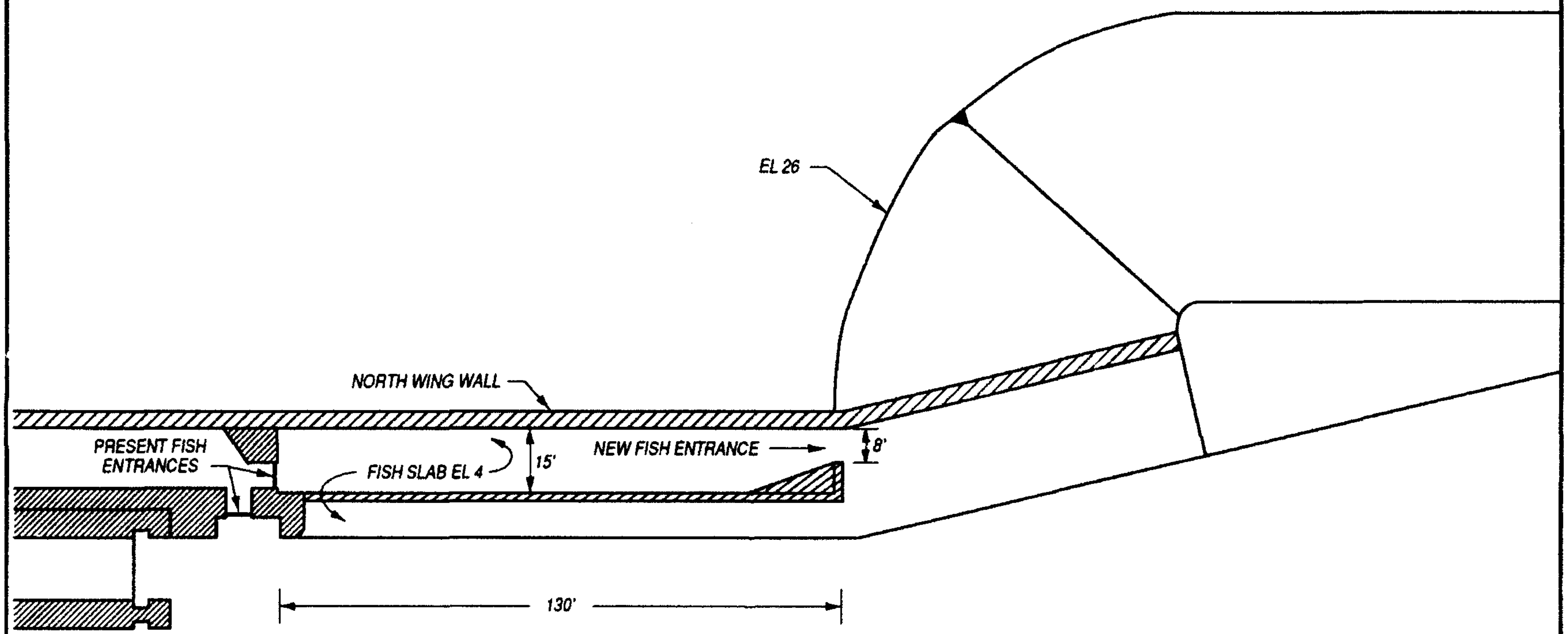
VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 8,200 CFS, UNIT 1 OPERATING
FISH ATTRACTION FLOW 500 CFS
TAILWATER EL 16.6
VELOCITIES MEASURED AT EL 10



PLAN

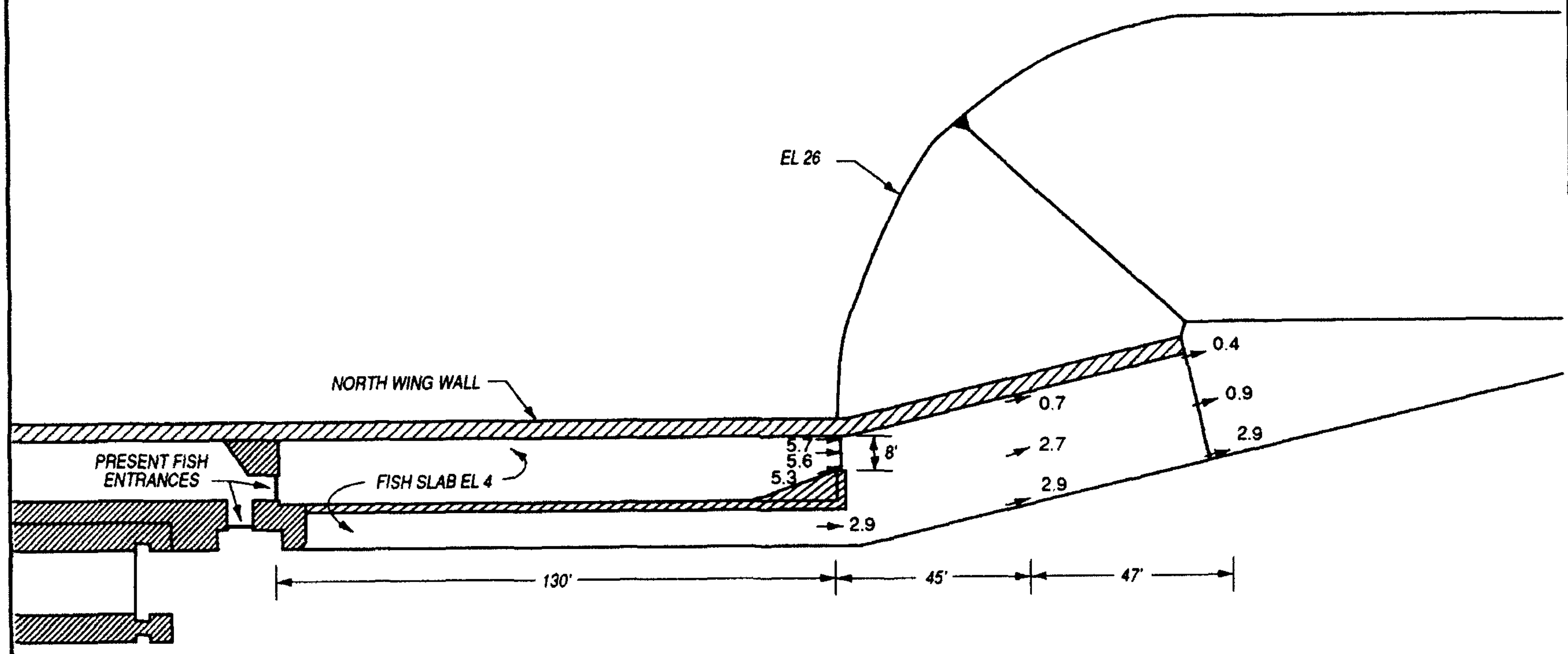
NOTE: VELOCITIES GIVEN IN FEET PER SECOND

VELOCITIES NEAR FISH LIFT
ORIGINAL DESIGN
DISCHARGE 8,200 CFS, UNIT 1 OPERATING
FISH ATTRACTION FLOW 500 CFS
TAILWATER EL 16.6
VELOCITIES MEASURED AT EL 15.5



PLAN

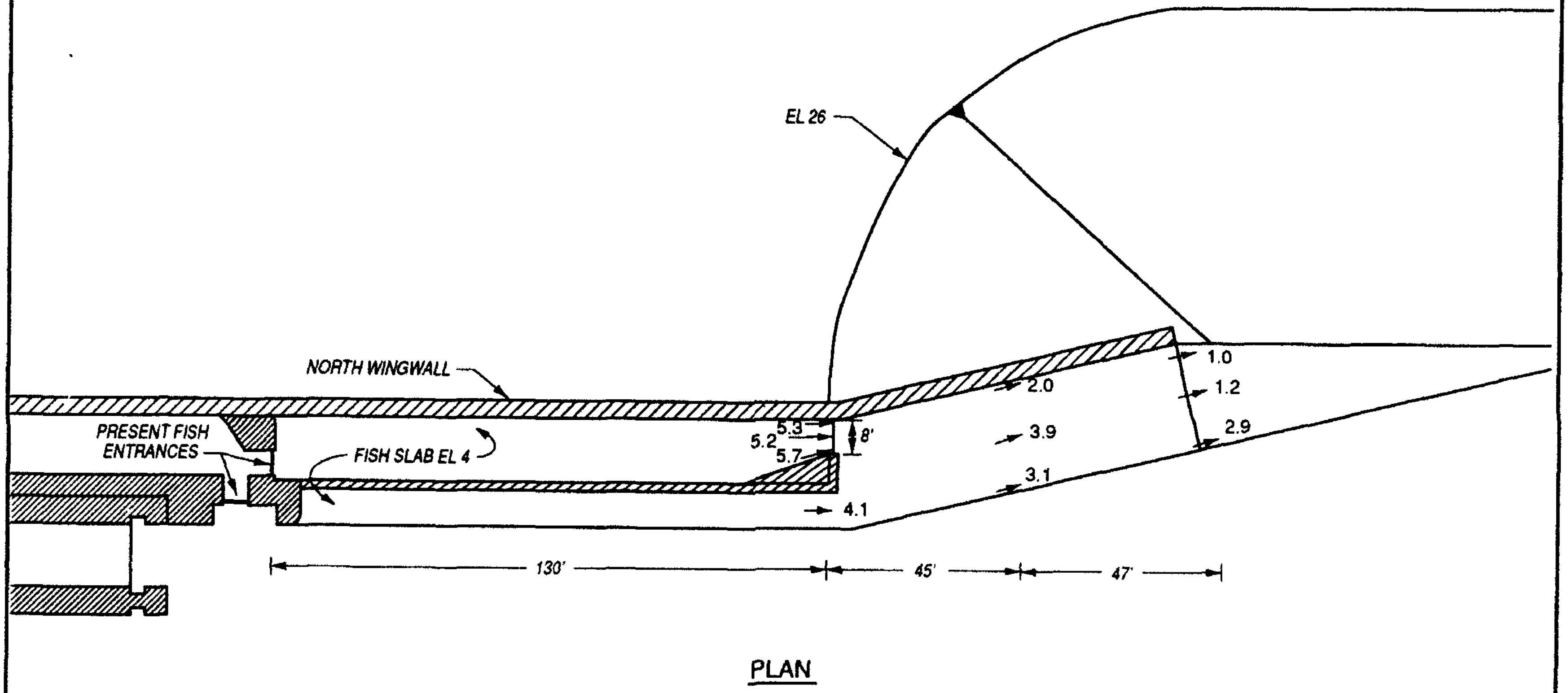
TYPE 1 ENTRANCE MODIFICATION



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

VELOCITIES
TYPE 1 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF FISH ENTRANCE WEIR EL 13.5
VELOCITIES MEASURED AT EL 20

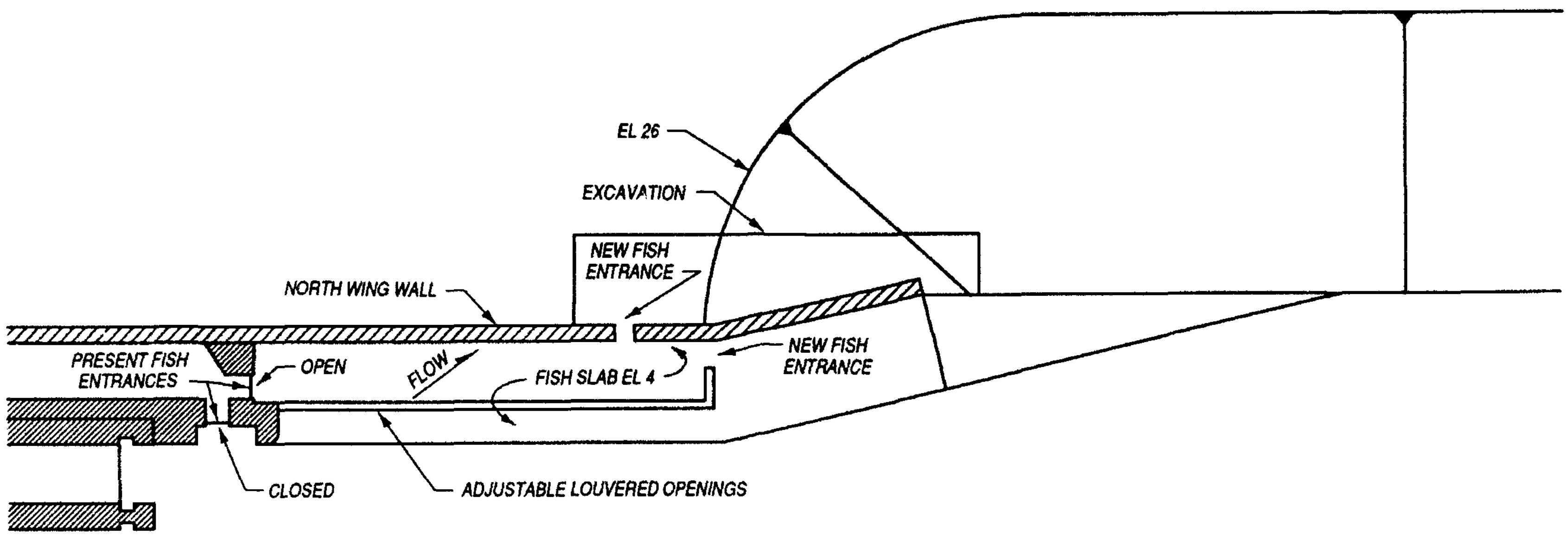


PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

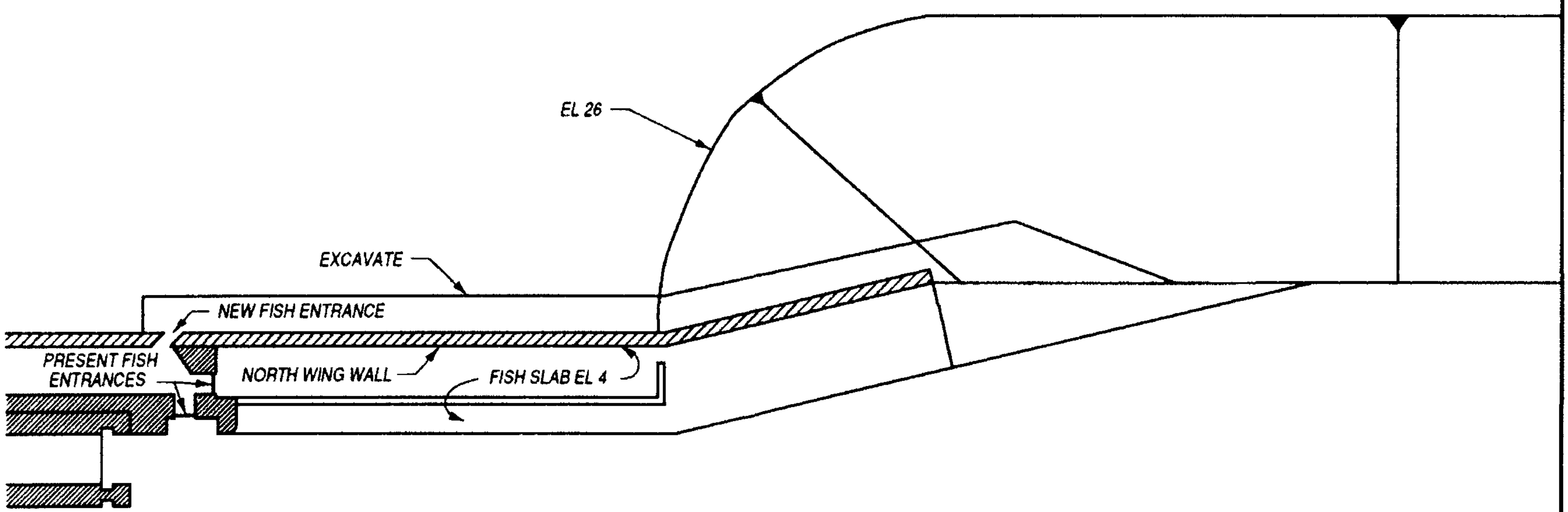
VELOCITIES

TYPE 1 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF FISH ENTRANCE WEIR EL 13.5
VELOCITIES MEASURED AT EL 25



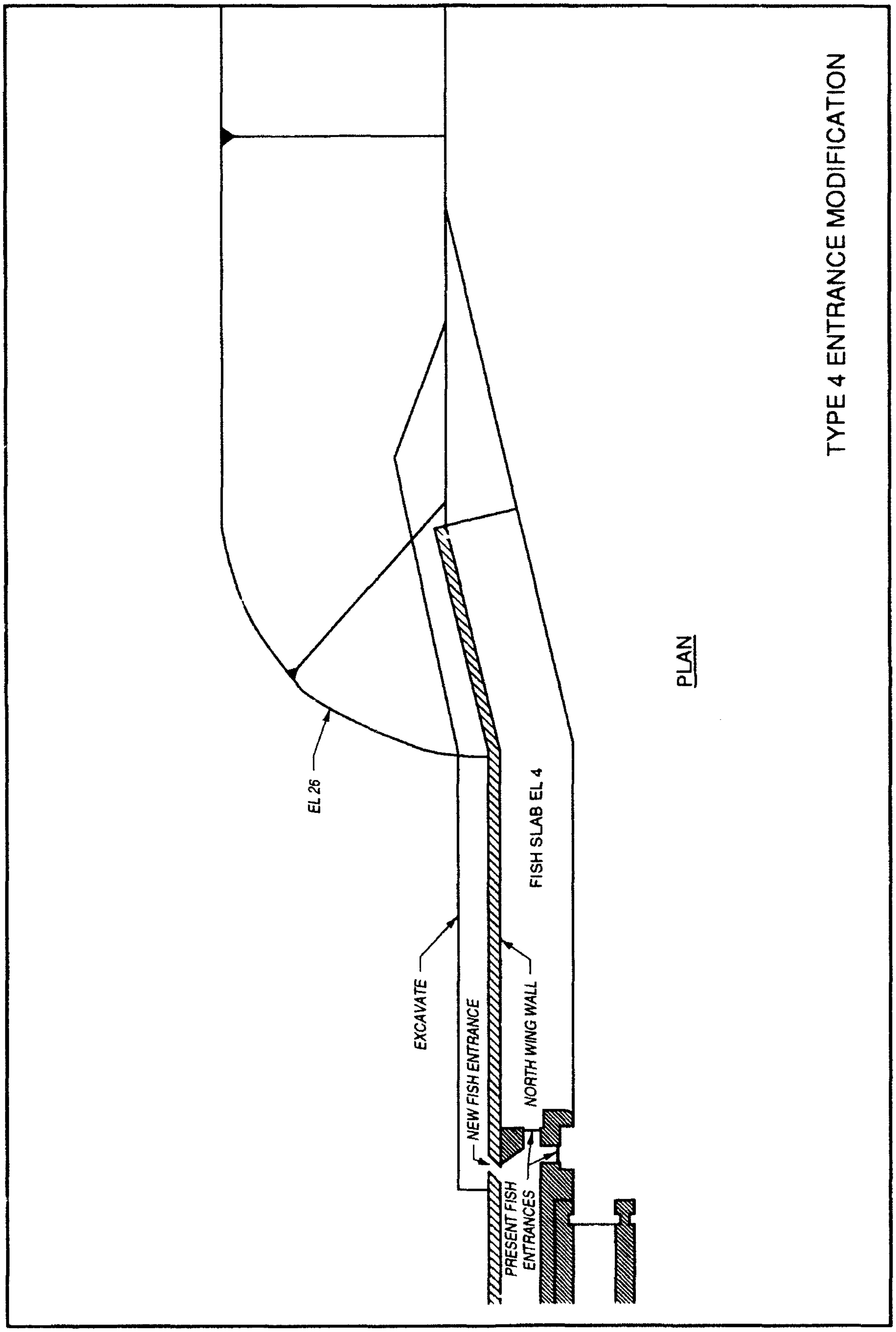
PLAN

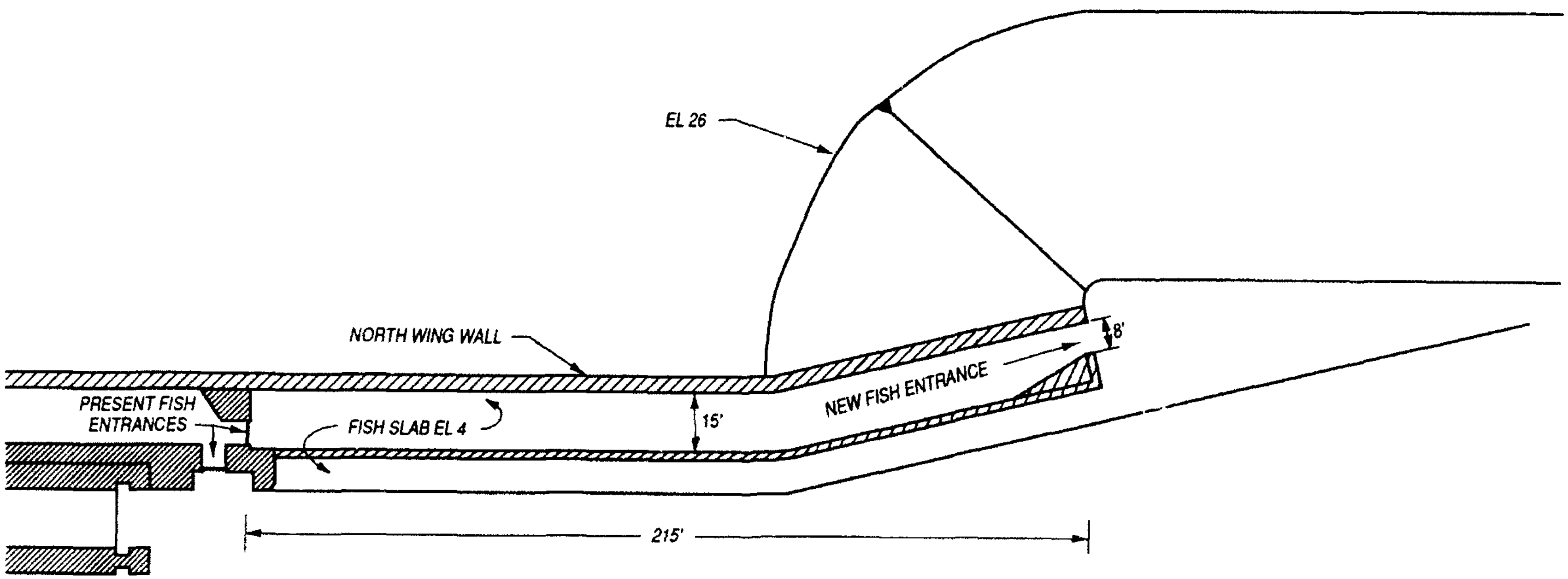
TYPE 2 ENTRANCE MODIFICATION



PLAN

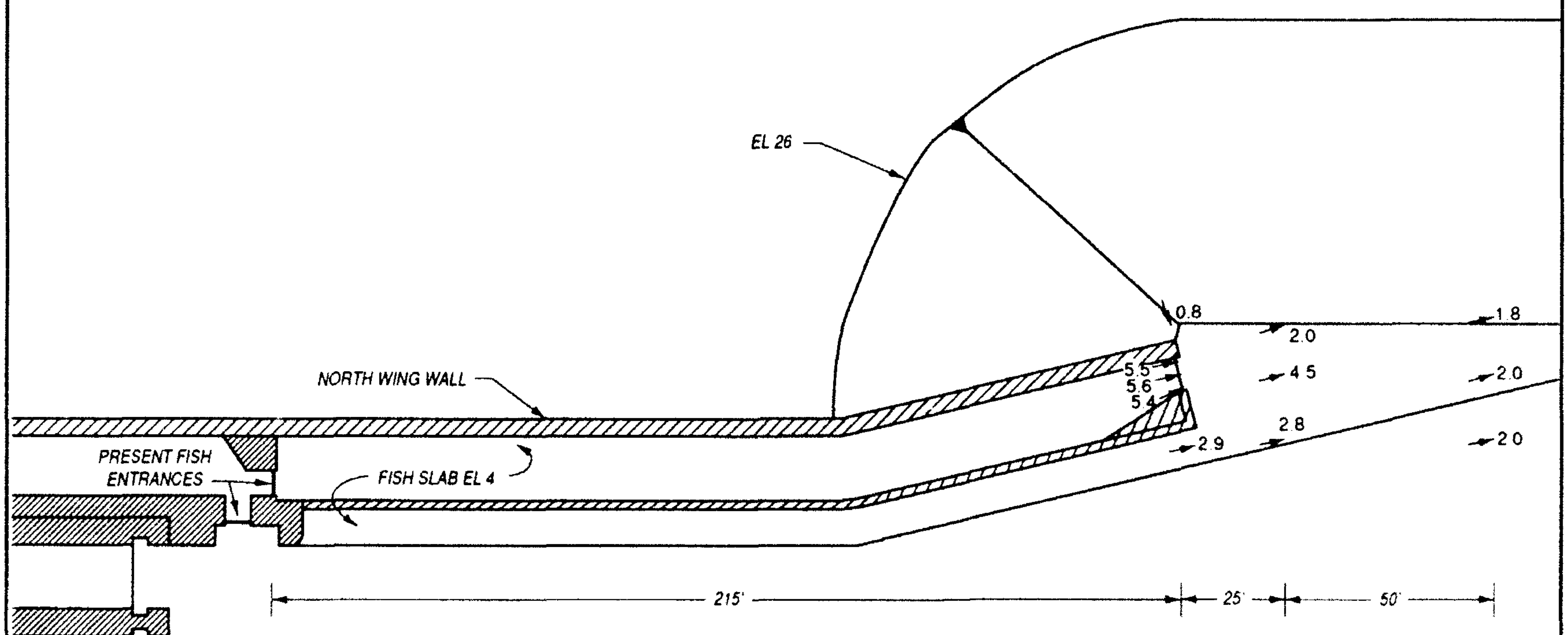
TYPE 3 ENTRANCE MODIFICATION


TYPE 4 ENTRANCE MODIFICATION
PLAN
EL 26
FISH SLAB EL 4
EXCAVATE
NEW FISH ENTRANCE
NORTH WING WALL
PRESENT FISH ENTRANCES



PLAN

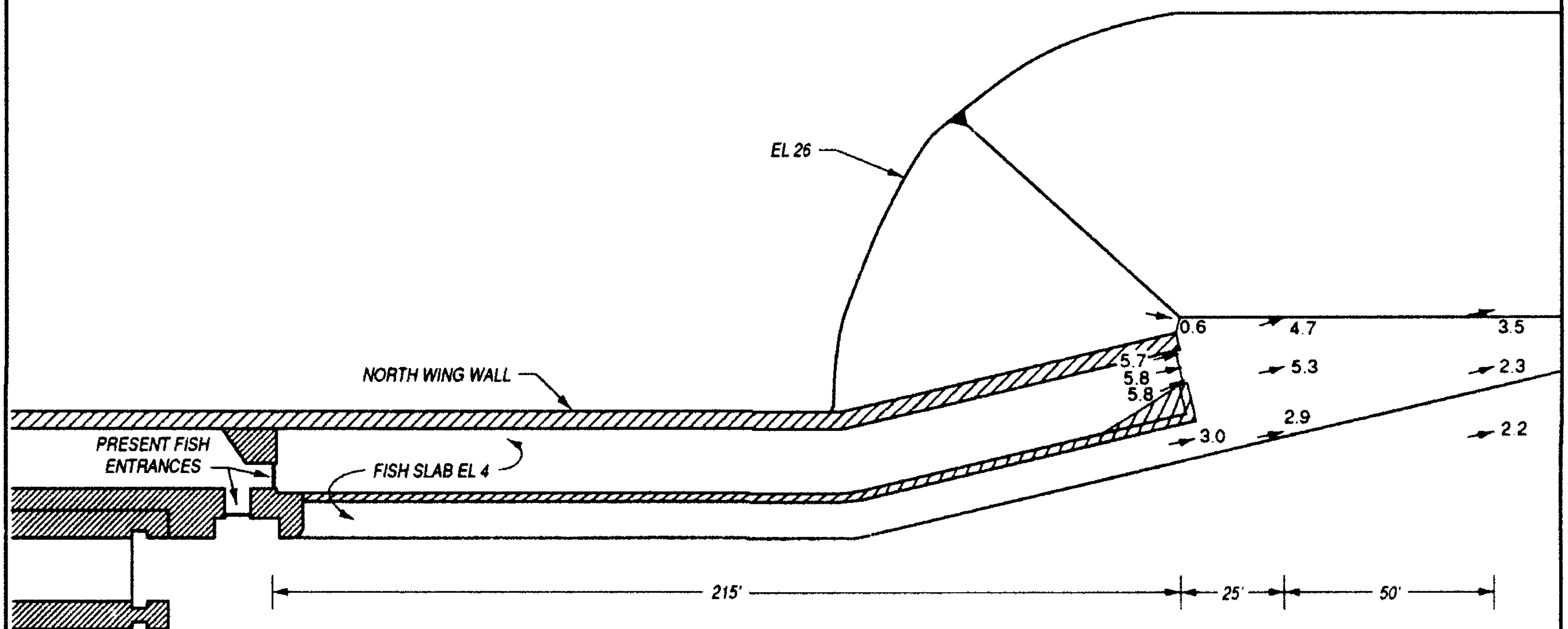
TYPE 5 ENTRANCE MODIFICATION



PLAN

NOTE. VELOCITIES GIVEN IN FEET PER SECOND

VELOCITIES
TYPE 5 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26 0, FISH ATTRACTION FLOW 500 CFS
TOP OF FISH ENTRANCE WEIR EL 13 5
VELOCITIES MEASURED AT EL 20



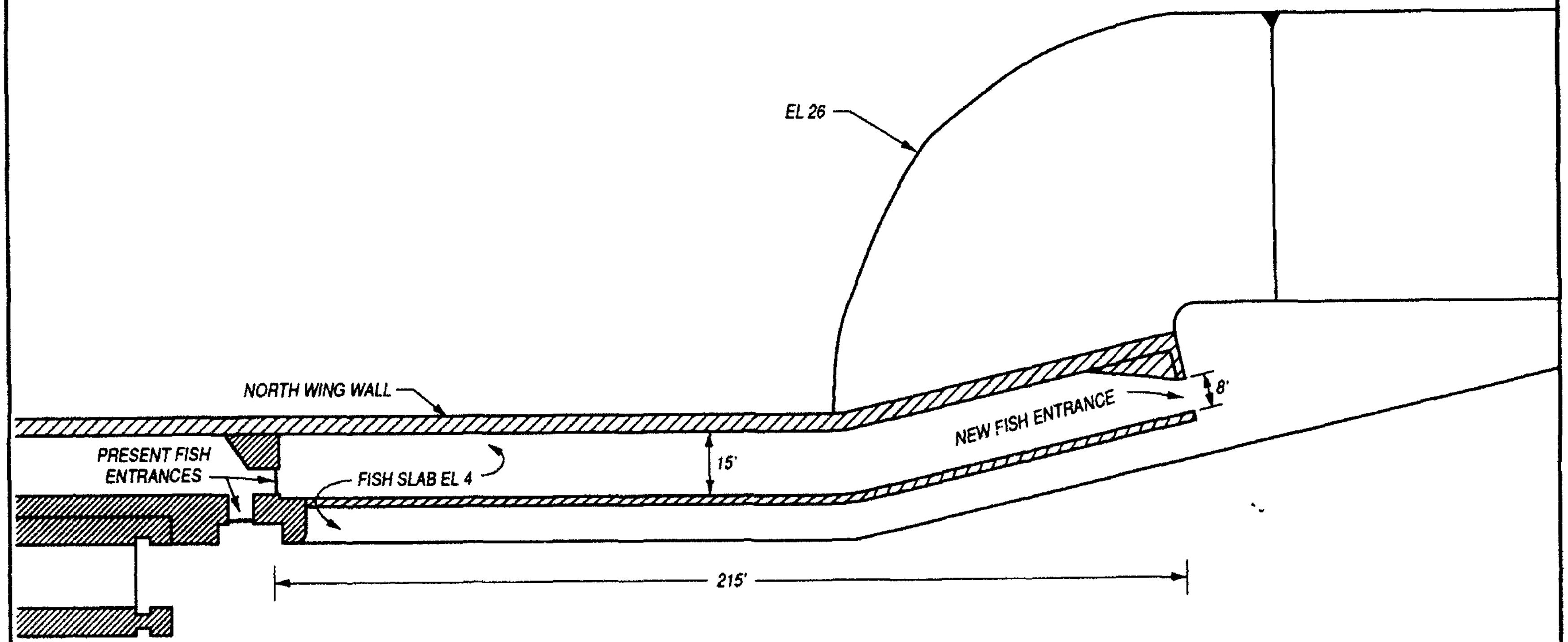
PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

VELOCITIES

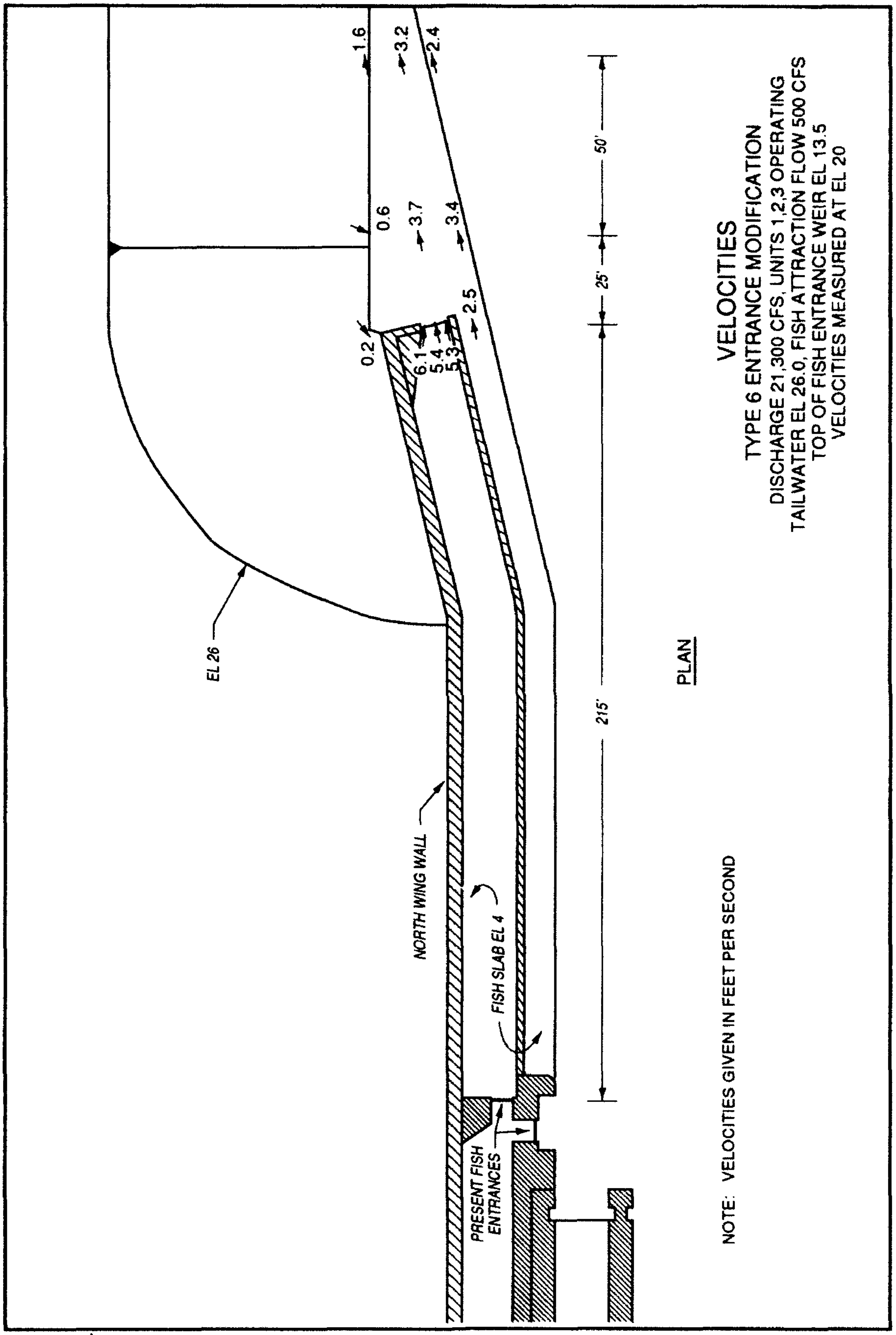
TYPE 5 ENTRANCE MODIFICATION

DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF FISH ENTRANCE WEIR EL 13.5
VELOCITIES MEASURED AT EL 25

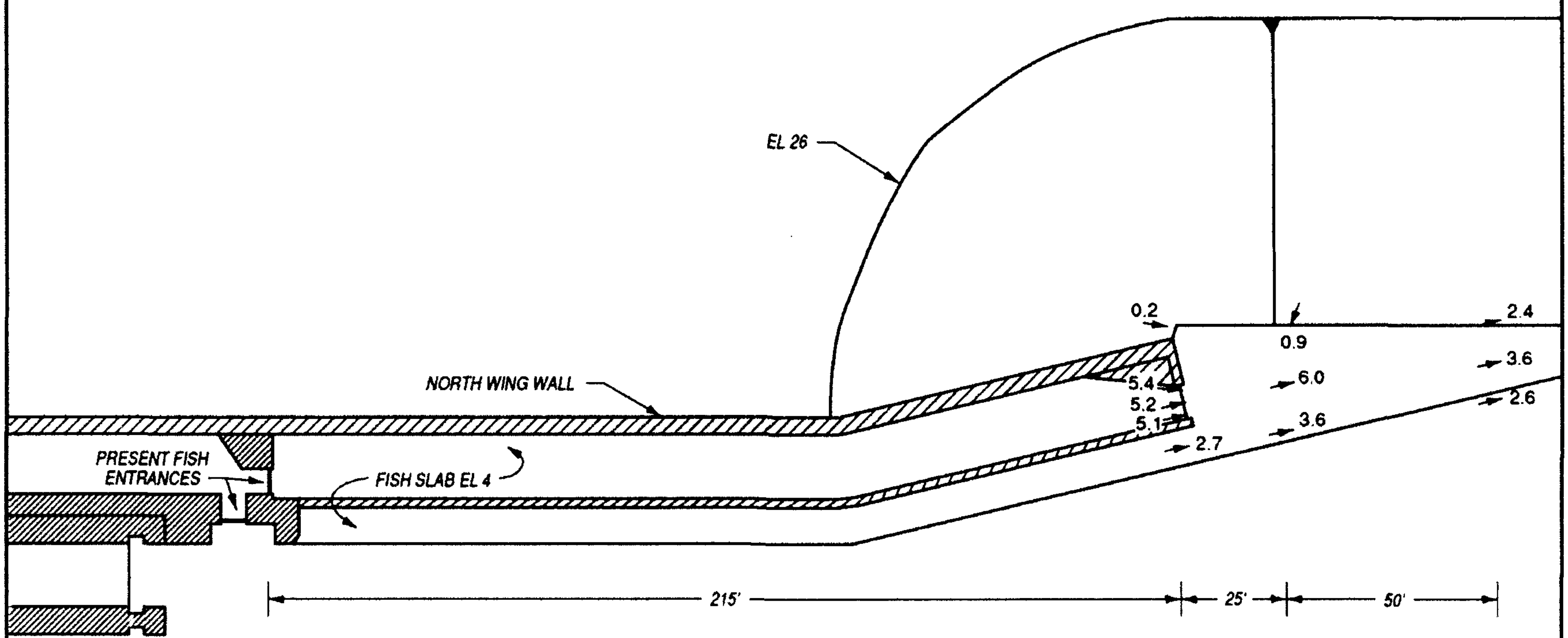


PLAN

TYPE 6 ENTRANCE MODIFICATION



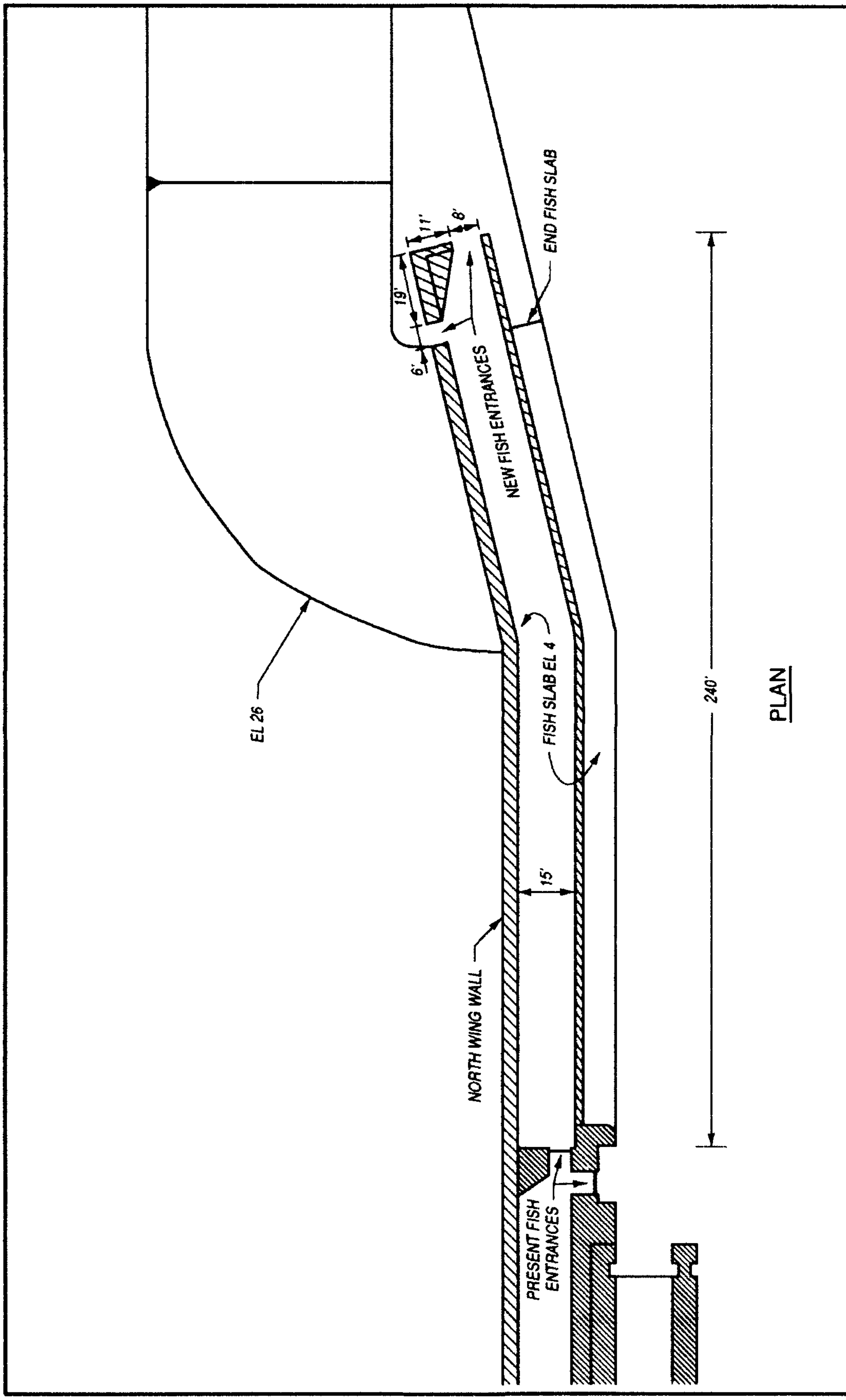
VELOCITIES
TYPE 6 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF FISH ENTRANCE WEIR EL 13.5
VELOCITIES MEASURED AT EL 20



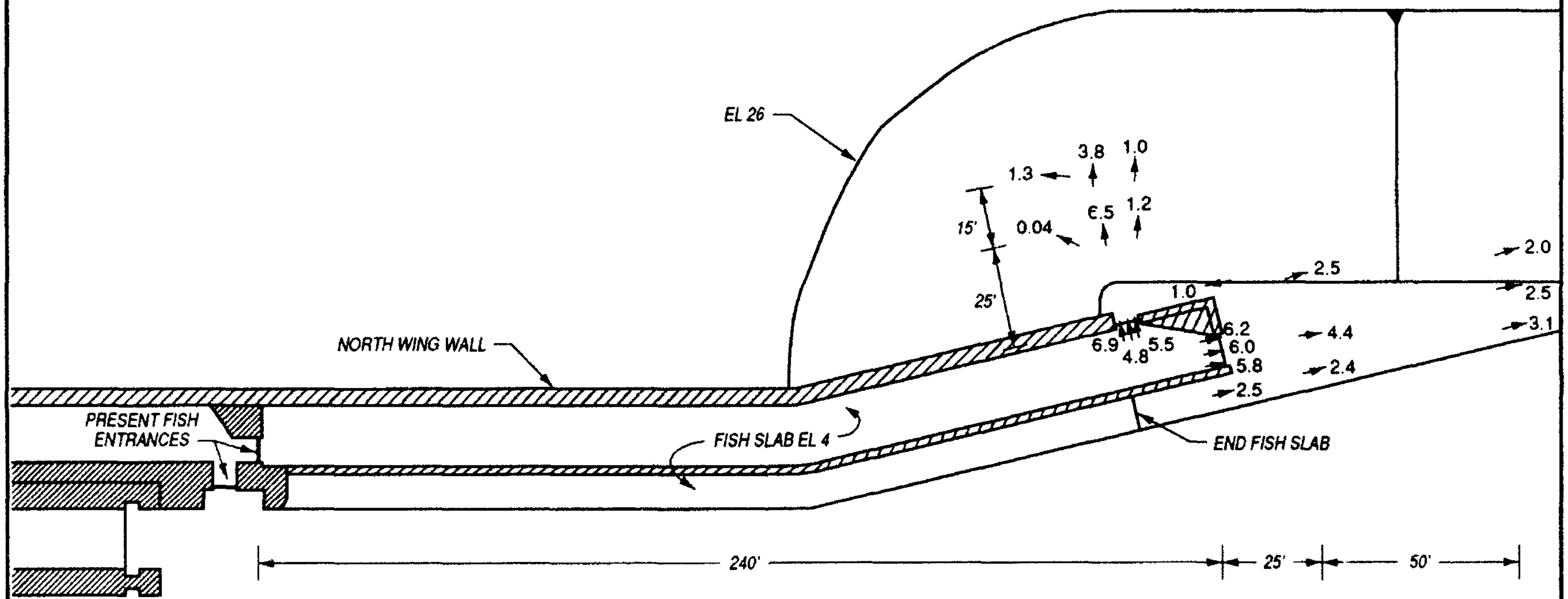
PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

VELOCITIES
TYPE 6 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF FISH ENTRANCE WEIR EL 13.5
VELOCITIES MEASURED AT EL 25



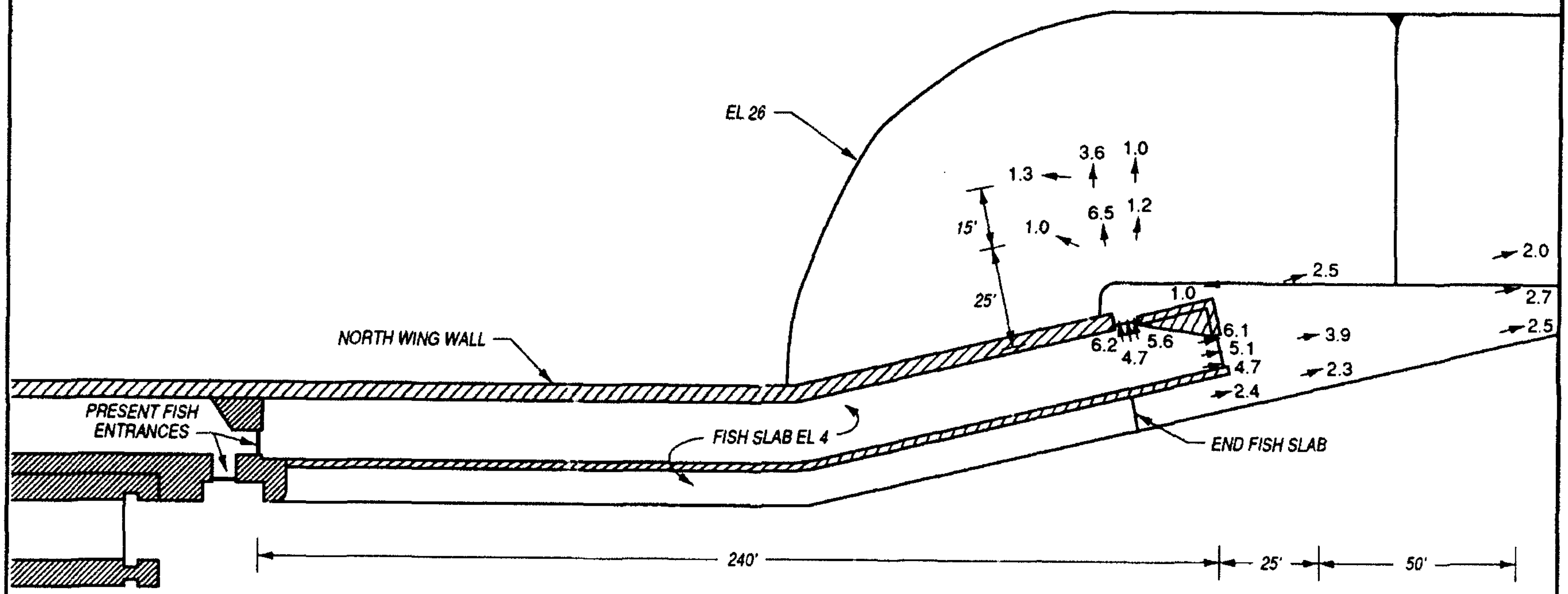
TYPE 7 ENTRANCE MODIFICATION



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

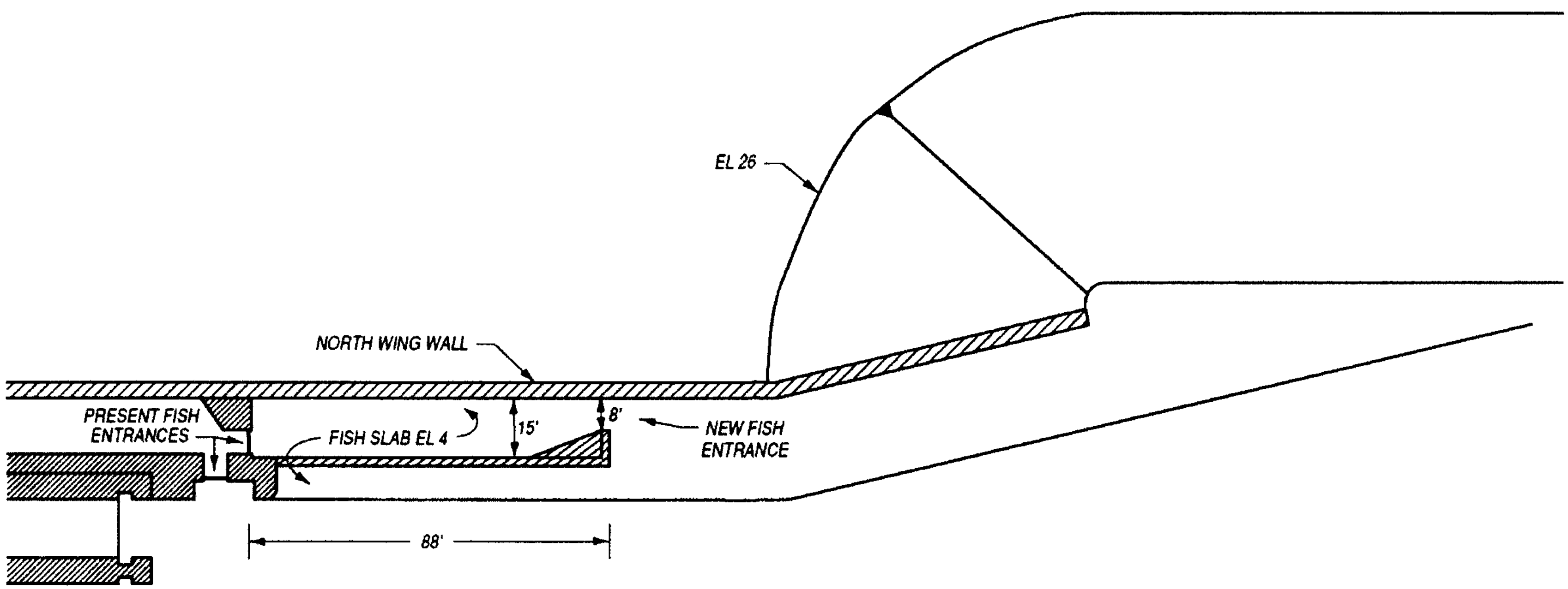
VELOCITIES
TYPE 7 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF UPSTREAM FISH ENTRANCE WEIR EL 19.3
TOP OF DOWNSTREAM FISH ENTRANCE WEIR EL 18.5
VELOCITIES MEASURED AT EL 22.5



PLAN

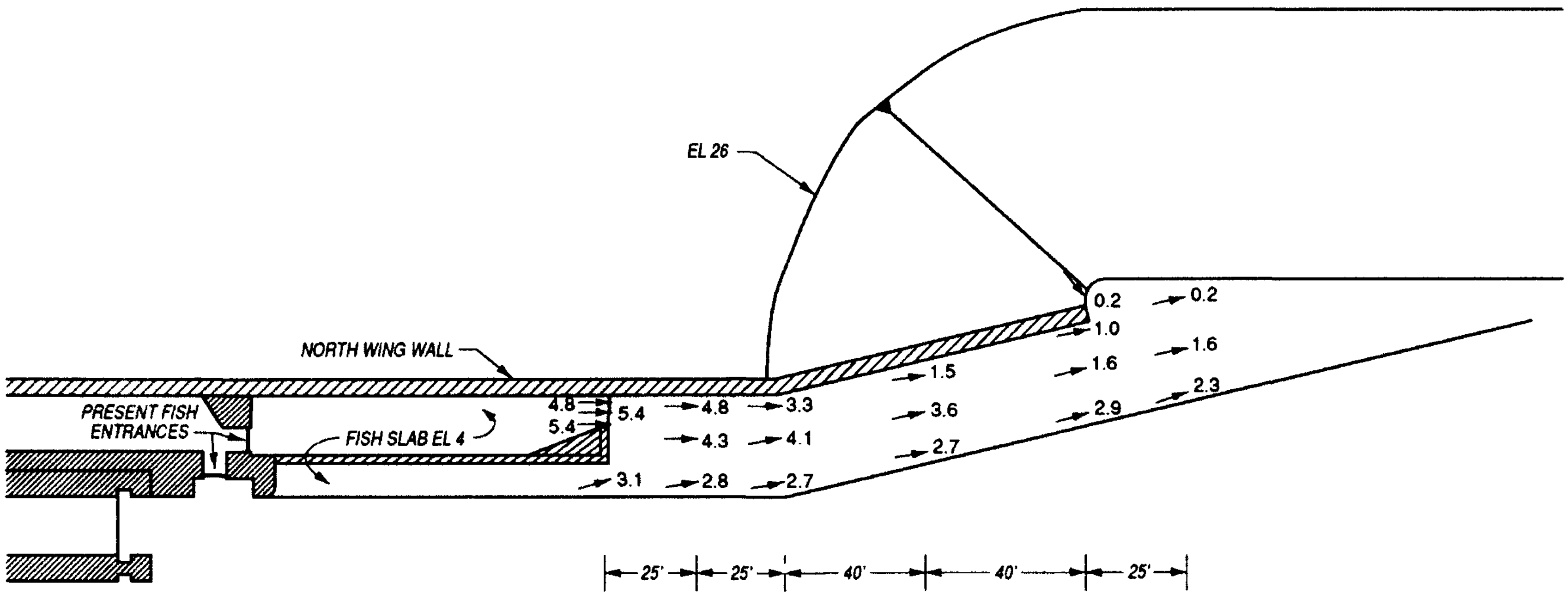
NOTE: VELOCITIES GIVEN IN FEET PER SECOND

VELOCITIES
TYPE 7 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF UPSTREAM FISH ENTRANCE WEIR EL 19.3
TOP OF DOWNSTREAM FISH ENTRANCE WEIR EL 18.5
VELOCITIES MEASURED AT EL 25



PLAN

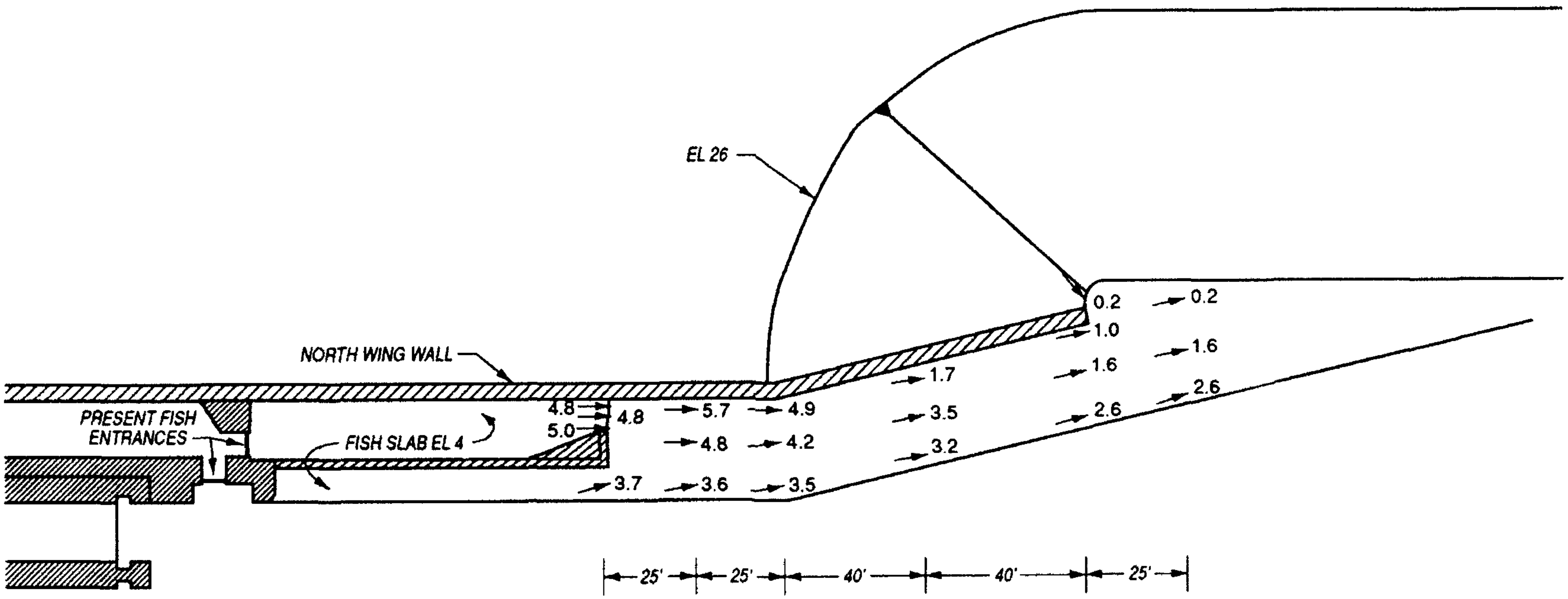
TYPE 8 ENTRANCE MODIFICATION



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

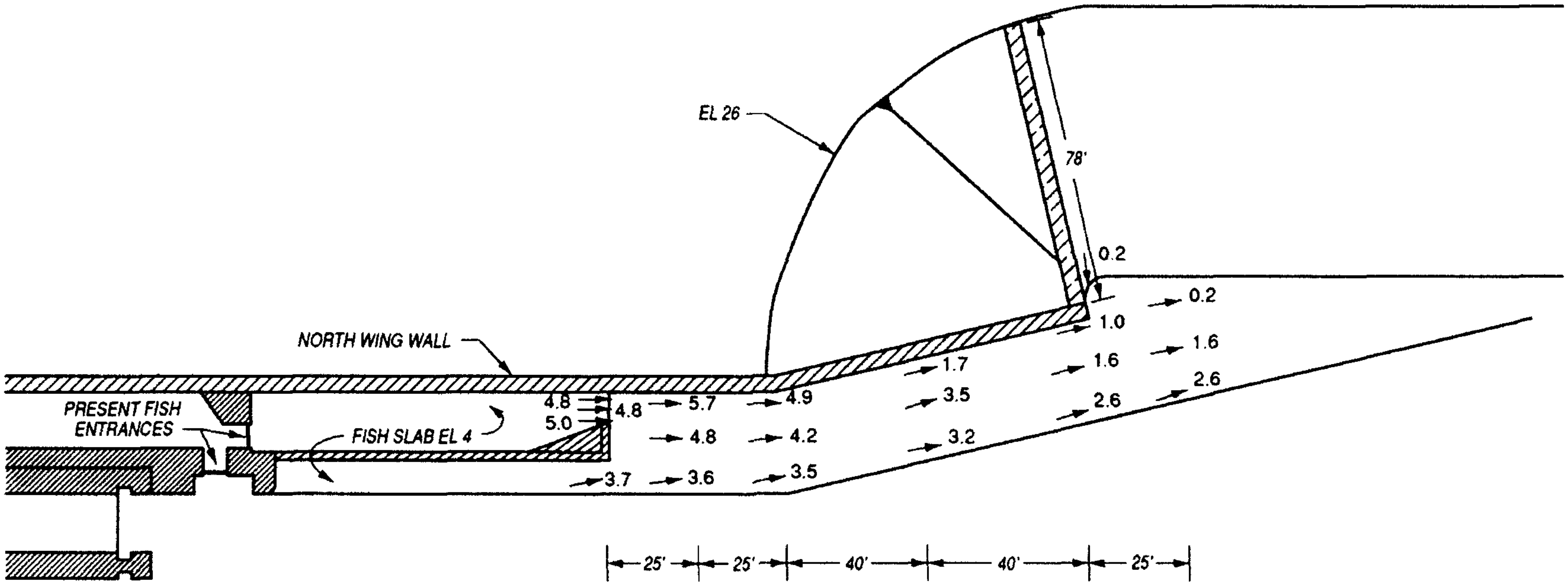
VELOCITIES
TYPE 8 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF WEIR EL 13.5
VELOCITIES MEASURED AT EL 20



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

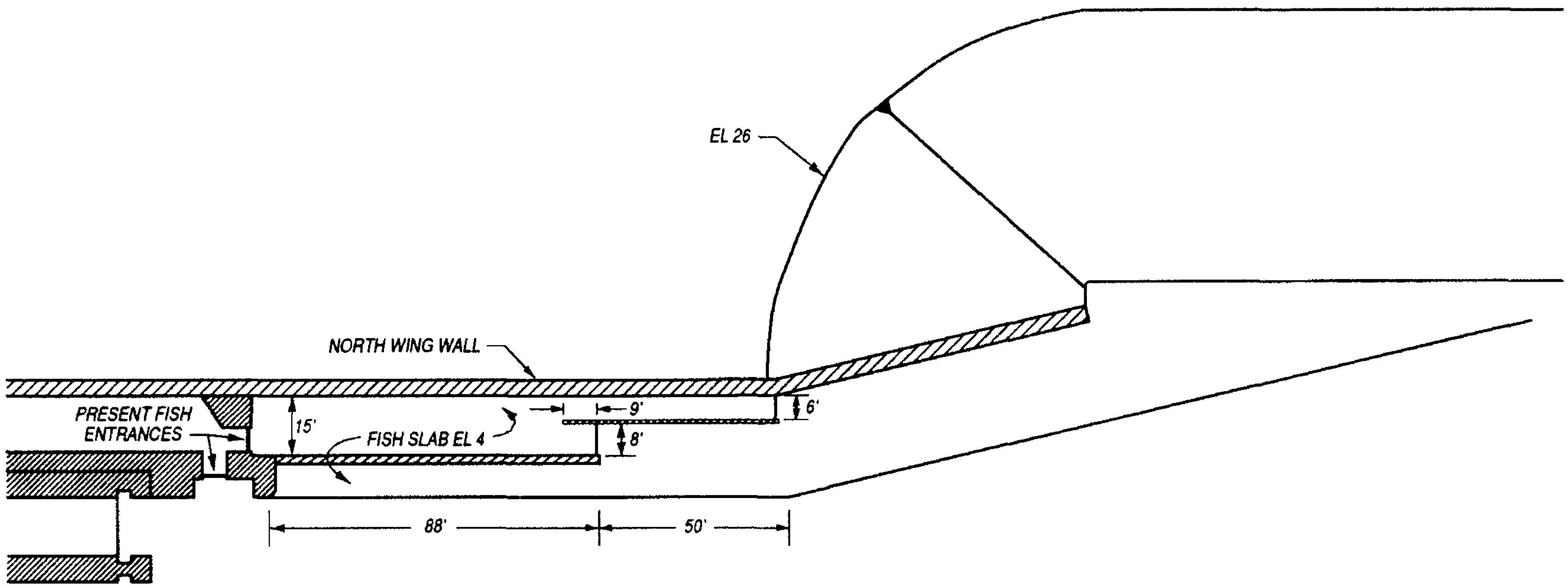
VELOCITIES
TYPE 8 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF WEIR EL 13.5
VELOCITIES MEASURED AT EL 25



PLAN

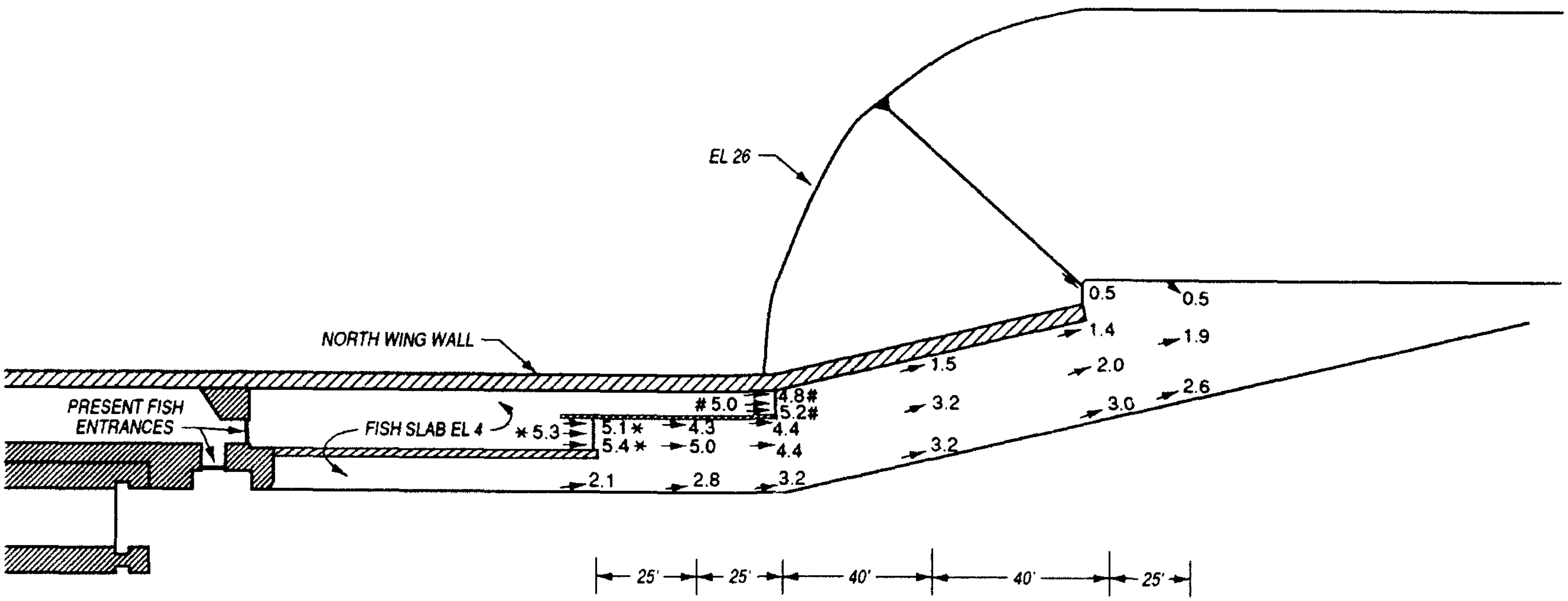
NOTE: VELOCITIES GIVEN IN FEET PER SECOND

VELOCITIES
TYPE 8 ENTRANCE MODIFICATION
EDDY AREA BLOCKED BEHIND NORTH WING WALL
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF WEIR EL 13.5
VELOCITIES MEASURED AT EL 25



PLAN

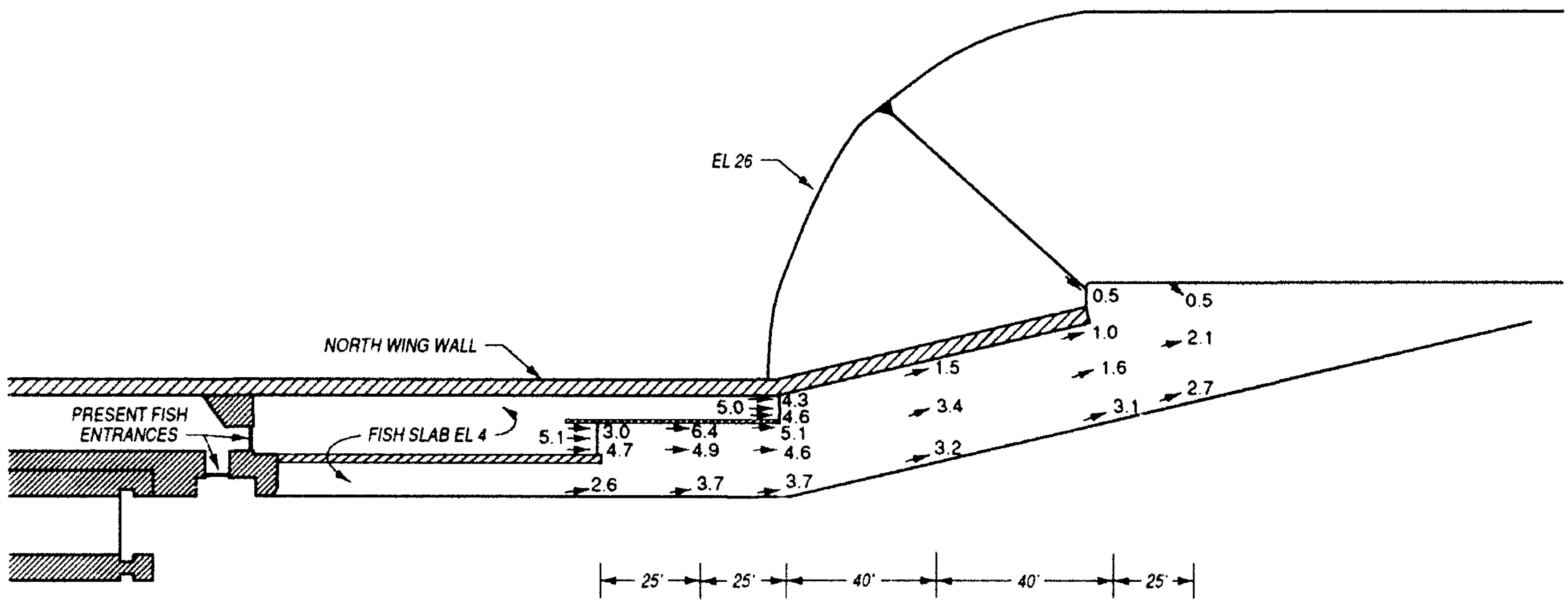
TYPE 9 ENTRANCE MODIFICATION



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND
VELOCITIES MEASURED AT EL 21.5
* VELOCITIES MEASURED AT EL 19.5

VELOCITIES
TYPE 9 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF UPSTREAM FISH ENTRANCE WEIR EL 16
TOP OF DOWNSTREAM FISH ENTRANCE WEIR EL 21
VELOCITIES MEASURED AT EL 20



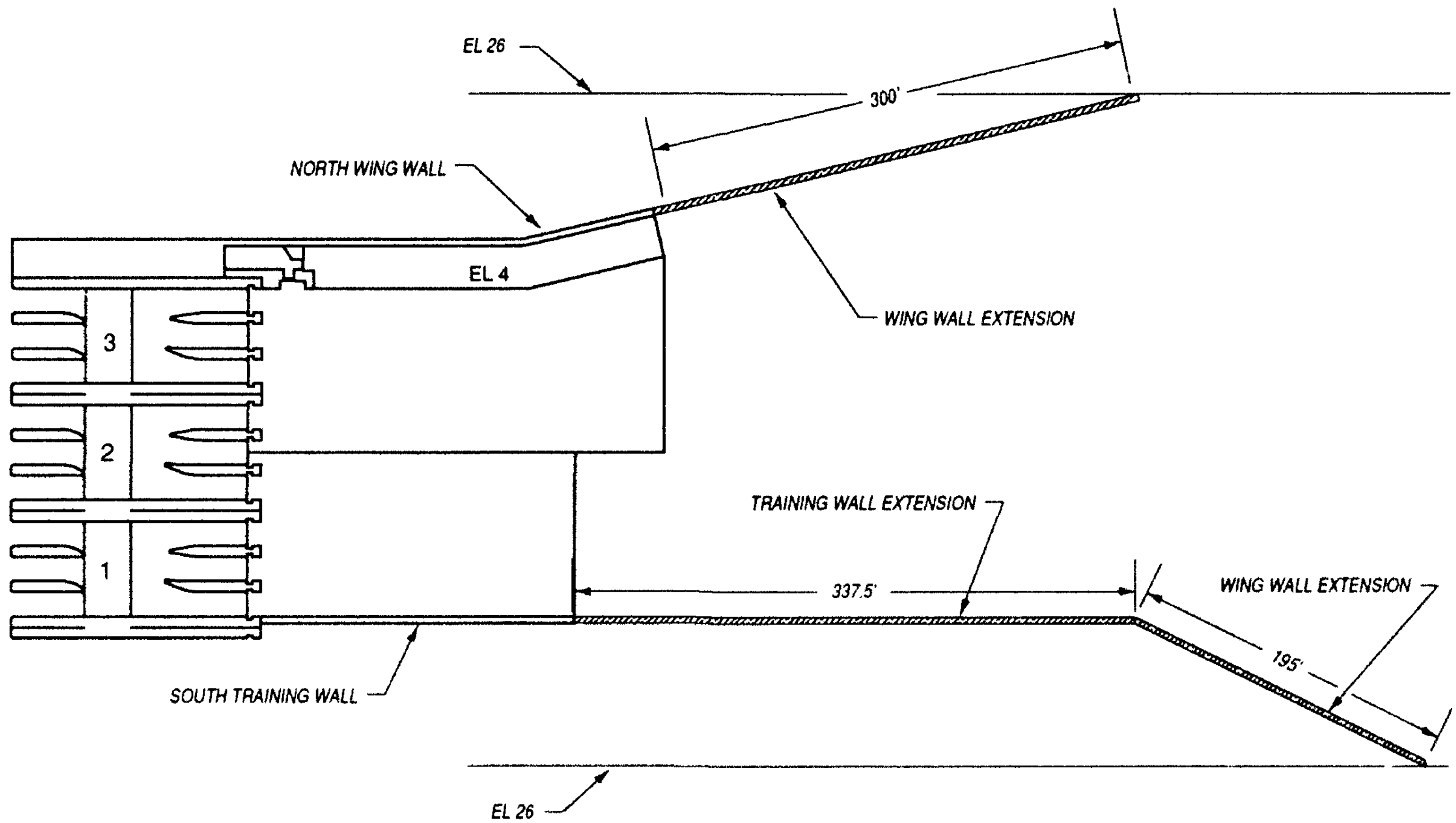
PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND

VELOCITIES

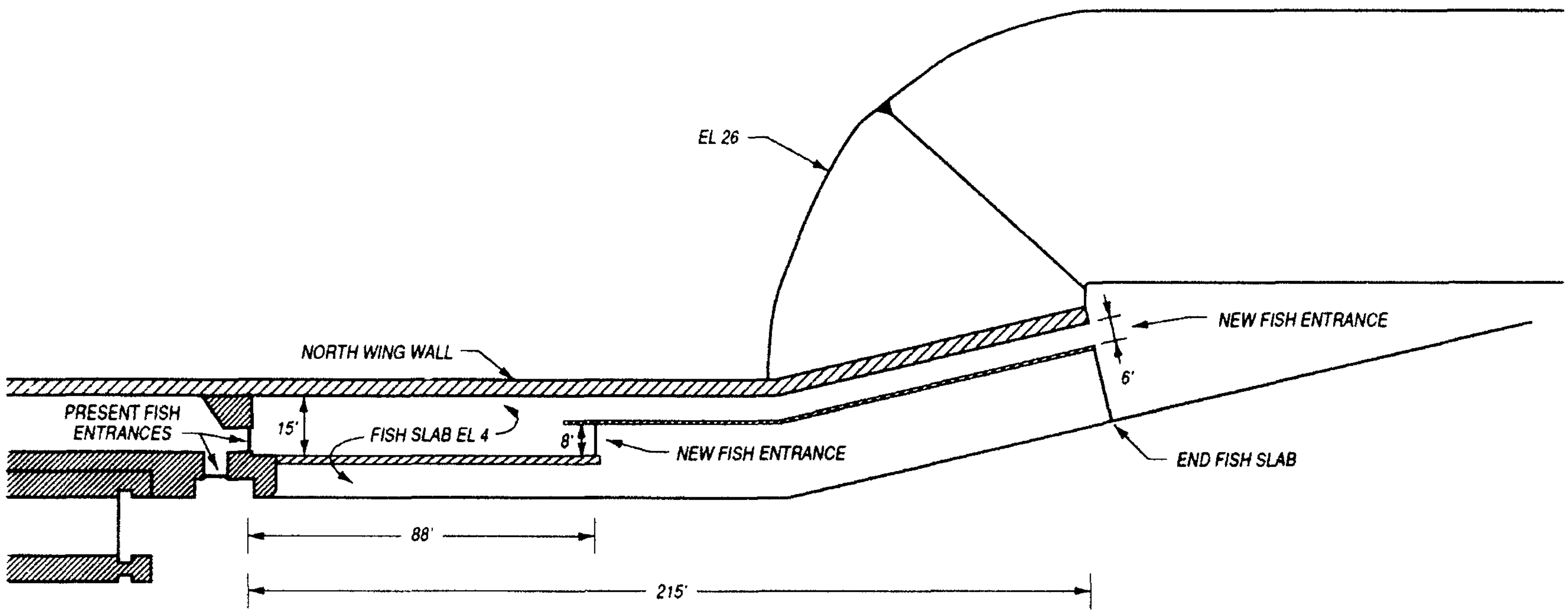
TYPE 9 ENTRANCE MODIFICATION

DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF UPSTREAM FISH ENTRANCE WEIR EL 16
TOP OF DOWNSTREAM FISH ENTRANCE WEIR EL 21
VELOCITIES MEASURED AT EL 25



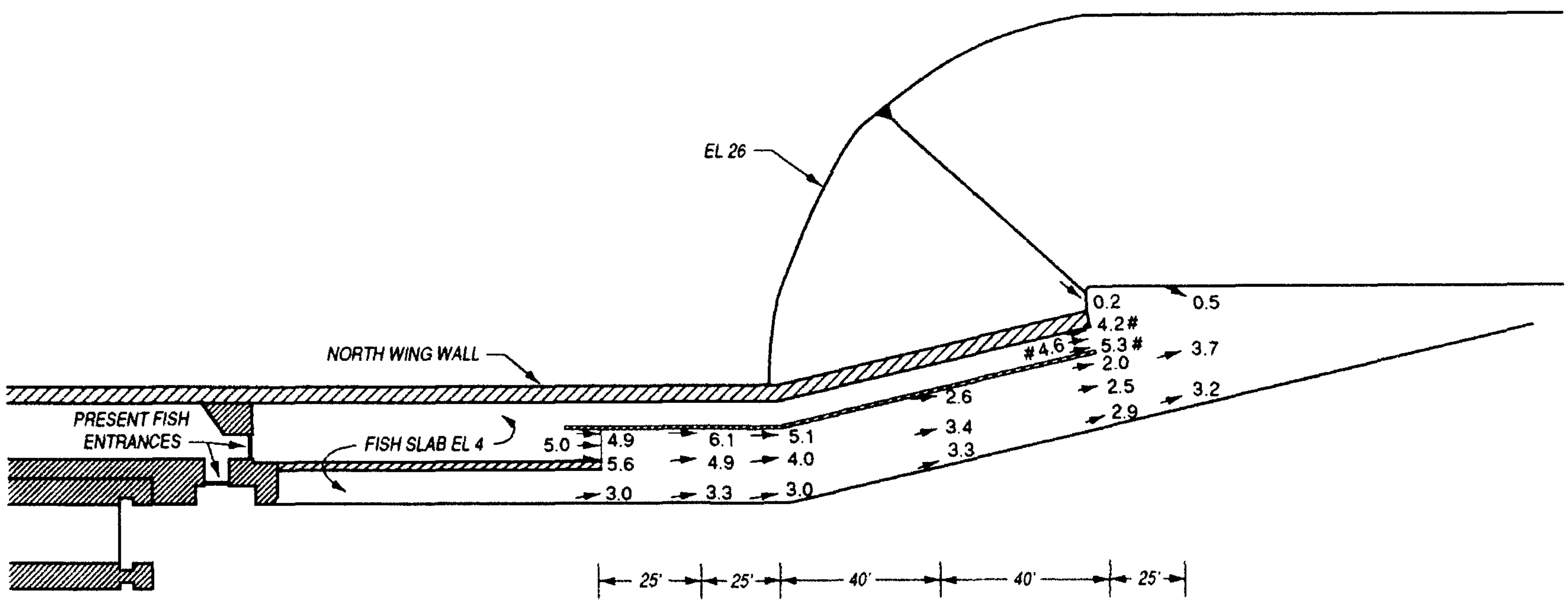
PLAN

TAILRACE WING WALL EXTENSIONS



PLAN

TYPE 10 ENTRANCE MODIFICATION



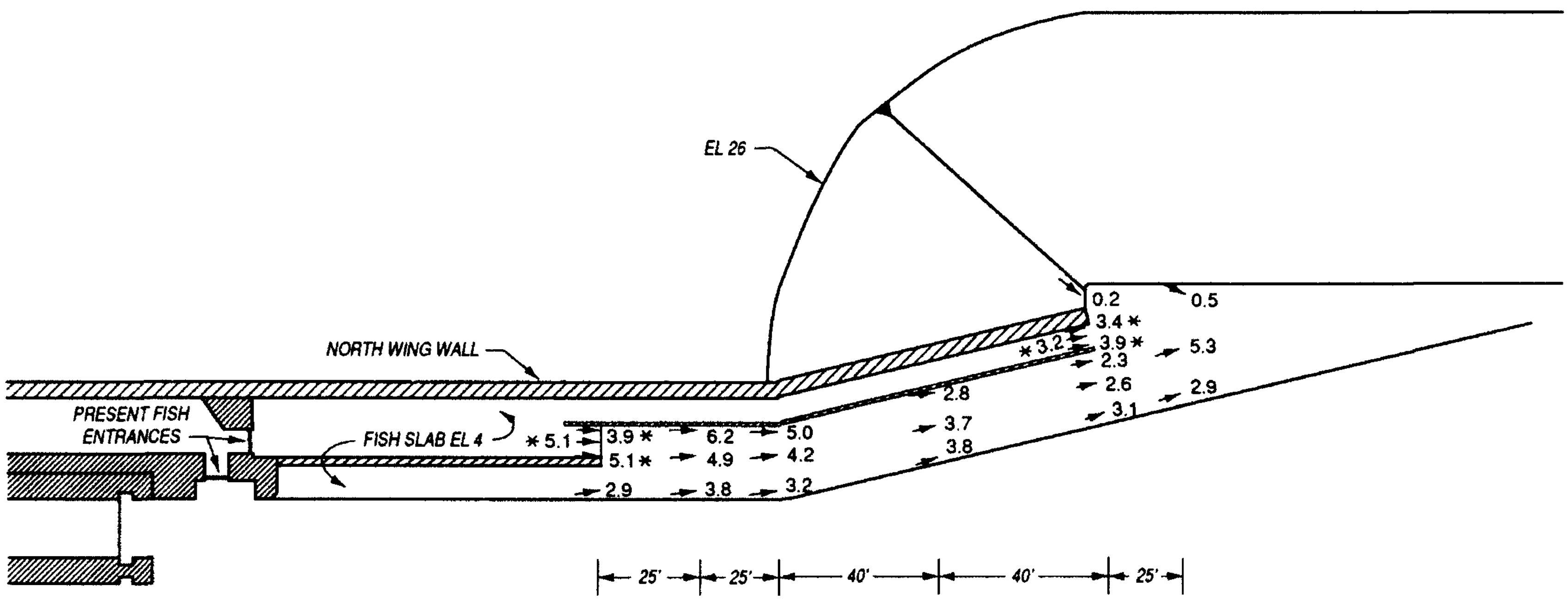
PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND
VELOCITIES MEASURED AT EL 23.5

VELOCITIES

TYPE 10 ENTRANCE MODIFICATION

DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF UPSTREAM FISH ENTRANCE WEIR EL 16
TOP OF DOWNSTREAM FISH ENTRANCE WEIR EL 21
VELOCITIES MEASURED AT EL 22.5



PLAN

NOTE: VELOCITIES GIVEN IN FEET PER SECOND
* VELOCITIES MEASURED AT EL 25.5

VELOCITIES
TYPE 10 ENTRANCE MODIFICATION
DISCHARGE 21,300 CFS, UNITS 1,2,3 OPERATING
TAILWATER EL 26.0, FISH ATTRACTION FLOW 500 CFS
TOP OF UPSTREAM FISH ENTRANCE WEIR EL 16
TOP OF DOWNSTREAM FISH ENTRANCE WEIR EL 21
VELOCITIES MEASURED AT EL 25

REPORT DOCUMENTATION PAGE

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12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

The St. Stephen Power Plant is located in Berkeley County, South Carolina, approximately 1.9 miles north of the town of St. Stephen. It is located in the rediversion canal connecting Lake Moultrie and the Santee River. Included in the project is a reinforced concrete fish lift structure located on the north side of the powerhouse. The present fish lift structure does not provide sufficient attraction flow in the tailrace area, where the desired numbers of fish are likely to be drawn into the fish lift system.

Tests were conducted on a 1:25-scale model of the powerhouse, fish lift entrances, and downstream tailrace canal. The purpose of the study was to investigate various alternatives to improve the fish attraction capabilities of the existing fish lift system. Walls were extended downstream from the original design fish lift to provide new entrance locations in areas more suitably located for fish attraction. The type 9 entrance modification is the recommended design. This modification provided for two fish entrances. The upstream entrance was located approximately 88 ft downstream of the present fish entrances, and the downstream entrance was located approximately 130 ft downstream of the present fish entrances at the bend of the north wing wall. Both entrances provided downstream flow along a wall leading to the entrance.

14. SUBJECT TERMS

Draft tubes
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Hydraulic models
Powerhouse
Tailrace canal

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